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THE FORMATION OF COAL BEDS.

III.[1]

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THE ROCKS OF THE COAL MEASURES.

Coal beds, Devonian, Carboniferous, Mesozoic and Tertiary, alike, are associated with shales, sandstones and, in many cases, with calcareous beds, the last often containing a marine or a fresh-water fauna. Interior or limnic basins frequently bear close resemblance to paralic or coastal basins, so that distinction between the types becomes arbitrary in some great areas. In the Indiana-Illinois field, wide invasions of the sea appeared again and again throughout practically the whole period of accumulation. On the other hand, the Appalachian basin, almost land-locked during most of its history, experienced few invasions and those, of comparatively small extent, were confined to the earlier periods; in the later stages, the whole region was practically limnic.

Study of reports by observers in the several countries makes certain that conditions needed for formation of coal beds were to

[1] Part I. appeared in these *Proceedings*, Vol. L., pp. 1–116; Part II. in same volume, pp. 519–643.

all intents and purposes the same in all regions and in all periods, from the Devonian coals of Bear Island in the Arctic to the Tertiary coals of Wyoming or Trinidad; but the varying descriptions and explanations presented by students make equally certain that one cannot ascertain what the essential conditions are, if his investigation be confined to areas embracing a score or even several hundreds of square miles. The investigation must cover a great area, in which merely local features do not obscure those which are general and which actually bear upon the problem in hand. Such an area is the Appalachian Basin of the eastern United States, where one finds the Pennsylvanian or Coal Measures divided into

Dunkard	Greene
Wheeling	Washington
	Monongahela
Athens	Conemaugh
	Allegheny
Pottsville	Beaver
	New River
	Pocahontas

The order is descending.[2]

The Appalachian coal field, now embracing approximately 70,000 square miles of almost continuous deposits, occupies only a part of the original area. The deep synclinal basins of anthracite in eastern Pennsylvania are separated by 50 to 100 miles from the great bituminous region at the west, while southwardly one finds insignificant fragments along the eastern side until he comes to Georgia and Alabama. The greatest extent of the area of deposit was probably at the close of the Pottsville, when it reached from southern New York in west southwest direction to beyond central Alabama, more than 800 miles; at the north, it spread from the old Appalachian land, at the east, westward to beyond Newark in

[2] J. J. Stevenson, "Carboniferous of the Appalachian Basin," *Bull. Geol. Soc. Amer.*, Vol. 18, 1907, p. 178. The Pottsville is subdivided in this paper into Beaver and Rockcastle. I. C. White, in West Virginia Geol. Survey, Vol. I*a*, 1908, p. 13, has suggested that Rockcastle be replaced by New River and Pocahontas; this should be accepted, as Stevenson did not assign proper significance to Pocahontas, regarding it as merely a subordinate stage.

Ohio, while at the south it reached the western boundary of Alabama. The area of deposit at that time embraced not less than 200,000 square miles. The present outcrop approaches the western border at a few localities in Ohio and Kentucky as well as in Alabama, but for the most part it is two score or more miles east from the original limit. The eastern border is approached in the southern anthracite field of Pennsylvania and apparently it was not far eastward from the Pocahontas outcrop in Virginia; in Alabama, the eastern outcrop is not more than 25 miles from the original border on that side. But, in most of the space north from Alabama, the present continuous outcrop is from 30 to 100 miles west from that border as it probably existed at the close of the Pottsville. The Appalachian field included a small part of New York, more than two thirds of Pennsylvania, the western third of Maryland, nearly the whole of West Virginia, the eastern third of Ohio and Kentucky, with southwestern Virginia, eastern Tennessee, the northern half of Alabama as well as northwestern Georgia. Here then is an area of sufficient extent to provide ample illustration of purely local features and their relations to the effects of widely acting agents.

The Appalachian Basin.

The Appalachian basin, from its origin to the close of the Palæozoic, was the scene of frequent changes in the relations of land and water. Schuchert and Ulrich[3] have shown that such changes were merely commonplaces in the earlier periods. Those students are not in agreement respecting several matters, which have much interest from a philosophical standpoint, but they are in full agreement respecting all matters which concern the questions at issue here. As Schuchert has shown, the Appalachian basin originally was continuous with the broad Mississippi region and much of it was covered with sea. Toward the close of the Ordovician the Taconic revolution began, which, at the east, widened

[3] C. Schuchert, "Palæography of North America," *Bull. Geol. Soc. Amer.*, Vol. 20, 1910, pp. 427–606; E. O. Ulrich, "Revision of the Palæozoic Systems," ibid., Vol. 22, 1911, pp. 281–680.

Appalachia by additions along the western side from New England through Virginia, thus giving a great area on which erosion could work and did work, as evidenced by clastic sediments in the northern part of the basin. The Cincinnati uplift of authors, occurring at the same time, led to the elevation of Cincinnatia (of Schuchert), the western boundary of the basin. Contemporaneously, as indicated by Schuchert, a less conspicuous land area, Alleghania, appeared within the basin, rudely parallel to Appalachia and extending southwardly across western Pennsylvania and eastern Ohio. It was separated from Cincinnatia by the Ohio basin. During the Silurian, there was occasional communication across Cincinnatia with the Mississippi region beyond and the faunas indicate that the basin opened northwardly to the Atlantic ocean. The same type of evidence shows that the basin was divided by a land area in southern Virginia, so that there was a northern sea extending into New York, as well as a southern sea in Tennessee and Alabama.

Studies by many geologists make clear that the southern portion of Appalachia was unstable. Southward from central Pennsylvania, the early Devonian rocks are wanting along the eastern side, while in southern Virginia and thence southward only the lower beds of the Middle Devonian are found. In Alabama the Devonian, more than 8,000 feet thick in central Pennsylvania, is represented by only dark shale rarely exceeding 100 feet and, near its southern limit, varying from 3 to 30 feet.

The area embraced in Schuchert's Alleghania was of decided instability. It received deposits during the Chemung, for that formation with its characteristic conglomerates crossed the area, though with reduced thickness; but all the principal elements of the section observed in central Pennsylvania are present. The intervals decrease toward this area and there is notable thinning above the upper conglomerate. The Catskill beds, following the Chemung, thin out against Alleghania, showing that once more it was above water. That formation, as defined by Vanuxem, the first to assign a definite meaning to the term, is 3,900 feet thick in Fulton county of Pennsylvania; 3,000, in the eastern portion of Bedford; 1,980 in western Bedford; it is concealed in Somerset,

except on the western edge, where it is brought up by a great anticline and is 10 to 15 feet thick, while, at 4 or 5 miles farther west in Fayette county, it has disappeared and the Upper Pocono beds of the Mississippian rest on the Chemung. The rate of decrease under Somerset is very nearly the same as that in Fulton and Bedford. This thinning is shown on the western side of the Catskill deposits from New York to New River in Virginia, beyond which southwardly Chemung and Catskill both disappear.[4]

The Carboniferous was opened by subsidence in the basin. The northern portion still received the greatest deposits along the eastern side in the old valley or "trough of sedimentation," but the area widened westwardly so that the later Pocono rocks of Pennsylvania overlap the Catskill of the Devonian and rest without apparent nonconformity on the Chemung rocks of Alleghania, as they do beyond in the Ohio basin. There was distinct widening eastwardly in Virginia and southward. Campbell[5] showed that phenomena in Virginia, which had puzzled earlier observers, were due to overlap; that the coal-bearing Mississippian deposits rest there on Ordovician rocks, which in all probability had been upraised during the Taconian revolution. Still farther south, the oldest rocks of the Mississippian overlap the Catskill, the Chemung and, at length, even the thin Chattanooga shales, the last Devonian representative toward the south. But during succeeding stages of the Mississippian, there was distinct contraction of the area of deposit on the western side, for the Maxville lies within the Logan and the Shenango within the Maxville;[6] at times, there may have been dry land in the Alleghania region. But at the south there was continued depression,

[4] J. J. Stevenson, "Bedford and Fulton Counties," Second Geol. Surv. of Penn., 1882, pp. 73–75, 81; "The Upper Devonian Rocks of Southwest Pennsylvania," *Amer. Jour. Sci.*, III., Vol. XV., 1878, pp. 423–430; "On the Use of the Name Catskill," ibid., Vol. XLVI., 1893, pp. 330–337.

[5] M. R. Campbell, "Palæozoic Overlaps in Montgomery and Pulaski Counties, Virginia," *Bull. Geol. Soc. Amer.*, Vol. 5, 1894, p. 182.

[6] J. J. Stevenson, "Lower Carboniferous of the Appalachian Basin," *Bull. Geol. Soc. Amer.*, Vol. 14, 1903, p. 85. This paper, on pp. 89–96, contains a discussion of the varying geographical conditions during the Mississippian.

increasing southwardly, so that in that direction the thickness of the deposits increases until eastern Alabama is reached, where one finds progressive overlap and each deposit has its attenuated outcrop beyond that of its predecessor. Toward the close of the Mississippian, Alleghania was becoming better defined; all of the formations are present in most of it but they are very thin, nowhere more than 400 feet thick at the north, less than one fifth as much as in the anthracite region. Whether or not the Shenango shales of western Pennsylvania are synchronous with the upper red beds of the Mauch Chunk region cannot be determined, as a gap of 60 miles exists, from which the beds have been removed. Fossils are rare and insufficient for correlation; they make evident, however, that marine conditions prevailed in Alleghania, for the individuals obtained in southwestern Pennsylvania are large, well developed and thoroughly characteristic. The water was probably too shallow and too variable in distribution to permit abundant life; the sun cracks, ripple marks and other features indicate that these fine muds were spread out on mud flats, with constantly shifting areas of tidal waters. It is certain that withdrawal of the sea was continuous on the western side, so that before the close of Mississippian, the Ohio basin had become dry land and Alleghania had become once more a distinct ridge, dividing the basin longitudinally from New York to central Tennessee. But the withdrawal affected almost the whole of the Appalachian basin; and this withdrawal may have been caused by extensive deformation of the surface. While Alleghania was raised at the west, there was rejuvenation of Appalachia at the east. In the later Mississippian, the streams had reached base level along the borders, for only fine muds were carried into the basin; but the Pottsville opens with coarse deposits from Pennsylvania to Alabama.

The distribution and character of the Pottsville deposits[7] seem to place beyond doubt the assertion that at the beginning of the Pennsylvanian the whole basin, excepting at the southwest corner,

[7] D. White, "Deposition of the Appalachian Pottsville," *Bull. Geol. Soc. Amer.*, Vol. 15, 1905, pp. 267–282; J. J. Stevenson, "Carboniferous of the Appalachian Basin," ibid., Vol. 18, 1907, pp. 142–150.

was a land area. Ancient Appalachia at the east towered above the old trough of sedimentation, now become a broad valley with irregular surface, while at the west rose the flat-topped Alleghania, hundreds of feet high at the north and separated from Cincinnatia by the broad, shallow valley of the Ohio basin, which deepened southwardly. The eastern valley and the slope of Appalachia were drained by a river following the westerly side of the valley and finding its outlet at the south in Tennessee, where there still remained a considerable body of water. A gradually lengthening stream drained the western valley and found its outlet at the south in the body of water, which was continuous around the southern end of Alleghania.

The story of the Appalachian basin for the Silurian, Devonian and early Carboniferous is one of local deformations, of differential elevations and depressions, of alternating water and dry land areas, of sea invasions and expulsions or withdrawals. Similar conditions continued throughout the Pennsylvanian. The subsidence during the earlier stages was evidently differential, increasing toward the south. As one follows the New River formation along the face of the bituminous area, he finds not merely lower and lower beds but, in Alabama, also a vastly increased thickness in each member of the section, so that the mass, belonging apparently in greatest part to the New River, is greater than the whole column in the anthracite area, though that includes the Pottsville and at least two thirds of the Athens. The condition throughout the Pottsville was that of subsidence and the area of deposit constantly increased toward the west. Along the sides of Alleghania and in the Ohio basin, the New River overlaps the Pocahontas and the Beaver overlaps the New River. The character of deposits in the anthracite region and in Alabama affords ground for belief that, while subsidence prevailed within the basin to the end of the Pottsville, there was interrupted elevation in much of Appalachia, causing frequent rejuvenation of the streams and preventing eastward expansion of the area of deposition. During the Athens and later periods, that area seems to have been contracting steadily, first at the south and eventually on all sides until, at the close of the Dunkard, completion

of the Appalachian revolution brought deposition to an end in the comparatively small area which remained.

Before presenting in detail the evidence on which these statements are based, it is well to call attention to a matter respecting which some misapprehension seems to exist. Time breaks in deposition, due to existence of a land surface, do not leave in every case a record in the way of non-conformity, which can be recognized in even a considerable area. Schuchert[8] has emphasized in this connection the conditions observed in the neighborhood of Louisville, Kentucky, where the limestone deposit is conformable throughout and appears to be continuous. The Devonian portion can be distinguished from the Silurian only by the fossils, although the portions are separated by a long land-interval. He offers many other instances to which the writer may add one, already referred to. In Westmoreland and Fayette counties of Pennsylvania, the Upper Pocono or Logan is shown resting conformably upon the Chemung, while at 60 miles east those formations are separated by not less than 4,000 feet of Catskill and Lower Pocono. Nor is it in any sense necessary that there be extensive erosion during a somewhat prolonged period of sub-aerial exposure, if the land be level or low-lying, even though the period be long enough to admit of the cutting of considerable valleys. Schuchert has shown that, though exposed during the whole period since the Taconian revolution, the Cincinnatian region has lost certainly little more than 400 feet by erosion and that in all probability the greater part of this loss has occurred since the Pleistocene elevation. Ulrich[9] says that a limestone in the St. Louis area, 5 feet thick, was exposed during the Silurian and the Devonian, yet it was not removed. Illustrations of the slowness of erosion, where land is level, are abundant in portions of Vermont, where one finds broad, terraced valleys in the Quaternary sands and gravels. The region has always been one with heavy rains, yet in some extended spaces the broad upper terrace is only slightly scarred, though, since it was aban-

[8] C. Schuchert, "Palæography of North America," pp. 441, 442.

[9] E. O. Ulrich, "Revision of the Palæozoic Systems," p. 306.

doned, the streams have cut their valleys, hundreds of feet deep, and have lined them with terraces.

The existence of a land area in Alleghania and the Ohio basin is made clear by the distribution of Pottsville deposits. The Pocahontas formation is present in the southern anthracite field and in the western part of the Western Middle, but it is wanting in the Eastern Middle and the Northern as well as in the bituminous region of Pennsylvania and Ohio. Along the eastern outcrop, it is present in the southern part of West Virginia and the adjacent part of Virginia, but it thins away quickly toward the west and northwest. It has not been recognized southwardly beyond Virginia. The New River is very thick in the southern and in the western part of the Western Middle, but is wanting in the northern anthracite field. It is very thick in eastern Alabama within the outlying areas, but it loses thickness quickly toward the west. This part of Alabama is a region of non-conformability throughout. Butts[10] has shown that that unconformity is found at close of Cambrian, Ordovician, Silurian and Devonian. There is notable non-conformity of erosion between Mississippian and Pennsylvanian. The sandstone and shale mass, closing the former in eastern Alabama, was removed from a great space prior to deposit of the Pottsville. In the continuous bituminous region, one finds the upper beds of the New River at about 70 miles south from the Pennsylvania line; the lower beds appear in succession until in the southern part of the state one finds, in all probability, the whole formation. The formation is wholly wanting in the northern part of the state and in by far the greater part of Pennsylvania. Indeed, there seems to be good reason for doubting the accuracy of identifications along the eastern outcrop in the latter state. In southern West Virginia it is possible to trace the formation across the state by means of exposures and the many records of oil-borings preserved by I. C. White. The lower members disappear in succession westwardly against the face of Alleghania and only the uppermost members

[10] C. Butts, "Iron Ores, Fuels, and Fluxes of the Birmingham District, Alabama," U. S. Geol. Surv. Bull., 400, 1910, pp. 14–16.

reach Kentucky. The formation can be followed easily along the eastern outcrop beyond central Tennessee, where the lower portion first crosses Alleghania, and becomes continuous with the deposit in the Ohio basin. There one finds the Bonair sandstone, midway in New River, passing across Alleghania, where it rests on Mississippian beds. On the western side in the Ohio basin, the higher New River beds disappear northwardly, each overlapped by its successor, so that beyond the Ohio River one finds only the topmost member occupying a long narrow space, extending almost to the present Lake Erie. At the close of the New River, most of the bituminous region within Pennsylvania and northern West Virginia was above the area of deposit. During the Beaver that area seems to have increased constantly so that, at the close of the Pottsville, Alleghania had disappeared and the Homewood sandstone or its equivalent covered the whole basin. The last portion of Alleghania to become buried was in Jefferson, Clearfield, Indiana, Westmoreland and Fayette counties of Pennsylvania. Differential subsidence continued throughout the Pottsville; even in the Beaver the condition is notable. That formation is 250 to 300 feet thick in western Pennsylvania, but on the Kanawha River in central West Virginia it is fully 1,000 feet, while in southwest Virginia the thickness seems to be even greater.

The Allegheny shows curious irregularities of thickness within the bituminous area, which are due clearly to local disturbances; but, leaving that feature out of view, one finds in a general way very little variation, except along the western border, where the section is shortened. The thickness may be taken as approximately 250 feet. In the anthracite area, the old trough of sedimentation continued and the great influx of materials from Appalachia gave a thickness several times as great. There, too, one finds anomalous deposition, with abrupt changes in structure of coal beds and remarkable variations in the intervals between them, evidence that there were many and serious local disturbances.

In the Conemaugh, there is less evidence of local disturbance. The variations are, as it were, regular. Measurements across the bituminous region show rapid thickening eastward to the Ohio

River but comparative uniformity thence to the eastern outcrop. In Muskingum and Guernsey counties of Ohio, the thickness increases from 315 to 340 feet but, 40 miles farther, at the Ohio it is 500 feet. In Pennsylvania and western Maryland the average is very nearly 600 feet. How thick the formation was in the northern anthracite field cannot be determined, as the top of the section has been removed, but the beds there are not less than 1,000 feet thick. The conditions were the same throughout the whole period of deposit, for variations in the upper half are similar to those in the lower half. Apparently there was slower subsidence along the western border than elsewhere, but no proof of overlapping or of regression can be found, as the outcrop is usually at a considerable distance from the border of deposit. There was a singular uniformity of conditions from north to south along the middle line of the bituminous area, a distance of more than 200 miles. At the most northerly outcrop in Pennsylvania, the thickness is approximately 600 feet and thence southward along the whole line it varies from 575 to 600 feet. Beyond Doddridge county of West Virginia, definite measurements cannot be made as coal beds and limestones alike have disappeared; but at Huntingdon, 100 miles beyond, and just west from the middle line the thickness is said to be 660 feet. At the extreme southeastern outcrop in West Virginia, the interval has been reported as 800 feet but some doubt remains as to the upper limit. Conditions during the Athens resembled those during the Pottsville, in that the trough of sedimentation with greater subsidence still existed at the east. But there was no longer differential subsidence toward the south and there is much reason for believing that there was notable contraction of the area of deposition in that direction, so that the Conemaugh may have extended, at most, only a short distance into Tennessee.[11]

But when one reaches the Wheeling he finds a notable change. Going eastward from the western outcrop in Ohio, the thickness

[11] The measurements of the Conemaugh have been taken from J. J. Stevenson, Ohio Geol. Survey, Vol. III., 1879; Second Geol. Serv. of Pennsylvania, Reports K, 1876, KK, 1877, T2, 1882; I. C. White, U. S. Survey, Bull. 65, 1891; West Virginia Geol. Surv., Vol. I., 1899.

of the Monongahela is 206, 250 and at the Ohio River 261 feet. Beyond that river, 275, 300, 340 and 380 in Pennsylvania to just beyond the Monogahela River; 316 at a few miles farther and 212 in the Frostburg basin of Maryland. Adding the coal beds and their partings one has 213 at the western outcrop, 270 at the Ohio River, 285 at western line of Pennsylvania, 400 near the Monongahela, 370 beyond the Monongahela and 252 in the Frostburg basin of Maryland.[12] It is evident that the topographical conditions have been changed and the area of deposit has become a trough with its deepest line midway in the bituminous region. The ancient trough of sedimentation at the east has disappeared. For in another direction the contrast with the Athens conditions is equally striking. No shortening of the section northward was observed in the Athens, but in the Monongahela, the shortening in that direction is distinct. Many measurements are available in southwest Pennsylvania and West Virginia.[13] These show that the thickness increases from 156 feet at the most northerly exposure in Washington county of Pennsylvania to about 400 feet at the West Virginia line, the increase being gradual. The extreme thickness is maintained in West Virginia for more than 50 miles. Thence the section can be followed only with difficulty as all horizons become indefinite, but evidently it becomes shorter, for, where the horizons again become definite, along the southern border, the thickness is 250 to 281 feet. The conditions were similar during deposition of the Washington. Throughout the Wheeling, the area of deposition was basin shaped, with the rate of subsidence increasing toward central West Virginia. It was contracting on all sides and there is little or no reason to suppose that any important deposits were made in the anthracite region or south from West Virginia.

[12] Ohio Geol. Surv., Vol. III., p. 262; Second Geol. Surv. Penn., Report K, pp. 211, 216, 240, 340; "Carboniferous of the Appalachian Basin," *Bull. Geol. Soc. Amer.*, Vol. 18, 1907, p. 47; G. P. Grimsley, "Ohio, Brooke and Hancock Counties," West Virginia Geol. Surv., 1907, p. 39.

[13] J. J. Stevenson, Second Geol. Surv. Penn., Rep. KKK, 1878, p. 292; a considerable number of measurements cited here from Rep. K were made by I. C. White; I. C. White, U. S. Survey, Bull. 65, pp. 54, 55; Well records in W. Va., Vol. I.

The area of Dunkard deposits seems to have been much less than that of the Wheeling, but erosion has stripped the borders and one can make few positive statements respecting the conditions. The full section, as it now exists, is found only at rare places in the long narrow strip within western Pennsylvania and West Virginia. There appears to be the same tendency to northward shortening of the section; there is evidence in Pennsylvania that there were local foldings, that, as in the earlier periods, there were not merely general movements leading to decrease of the area of deposition but also others due to strains varying in direction at different times.

Evidence of elevation and subsidence is found in buried valleys, marking the courses of subaerial streams. These are so numerous that one need select only a few instances.

That Alleghania and the Ohio basin were dry land at the close of the Mississippian, is clear from the evidence of erosion as well as of corrosion. Hyde[14] has summarized the observations of his predecessors and has added the results of his own studies. The base of the Coal Measures along the outcrop belt in southern Ohio rests directly on the Logan formations, which for the most part are Lower Mississippian. These were subjected to great erosion, which left a relief of 200 to 300 feet. Hyde followed this surface of unconformity across Ohio from the central line of the state southward to the Ohio River, finding frequent variations of 100 feet in the elevation. The Coal Measures sandstones are often let down into the Logan, but ordinarily the non-conformity is gentle. Here and there one sees old valleys which can be traced for considerable distances. The erosion was mostly post-Maxville.

Soon after the elevation of Alleghania and the Ohio basin, a stream began to cut for itself a valley, which, before the end of the New River stage, extended from the Canadian highlands southwardly across Ohio, Kentucky and Tennessee to an outlet at the

[14] J. E. Hyde, "Notes on the Absence of a Soil Bed at the Base of the Pennsylvanian of Southern Ohio," *Amer. Journ. Sci.*, Vol. XXXI., 1911, pp. 557–560.

southwest. This stream must have been determined very quickly after the region became dry land, for, before the end of the New River, it had made a terraced valley, at least 30 miles wide in some parts of its course and showing irregularities of surface which indicate existence of many minor tributaries. The main stream had its source in the Canadian highlands; an important tributary drained part of the Mississippian ridge of Michigan and its course lay within the area of Lake Erie; a second important tributary came from the east, draining a part of southwestern New York and northern Pennsylvania. In Ohio, this valley area is for the most part west from the present outcrop of Pennsylvania beds; but its eastern side is traced readily from 10 miles south of Lake Erie to the southern border of Summit and Portage counties, about 80 miles, for it is filled with coarse sandstone and conglomerate, which thin out abruptly at the east, permitting the overlying beds to rest on Mississippian rocks. The western edge is approached in Wayne and Medina counties, where the coarse beds become very thin. Fragmentary exposures of the eastern side are found in counties farther south until, in Vinton, Jackson and Pike, the Pennsylvanian outcrop swings westward and the exposures extend to apparently midway in the valley. Thence into Kentucky the outcrop again trends southwardly and only the extreme eastern border is seen. In northern Kentucky, another valley, now filled with New River beds, begins in Carter county at 20 miles south from the Ohio River and deepened rapidly southward in Mississippian rocks. Its direction, west of south, is such that, within a few miles from the last recorded exposure, it should unite with the main valley. In southern Kentucky on the western side of the Main Valley area, M. R. Campbell discovered a valley in Mississippian rocks, deepening toward the east and now filled with New River beds. Farther south, in Tennessee, the relations soon become indefinite, but observations on the eastern side by Hayes make sufficiently clear that the valley was distinct at half way to the Alabama line until midway in the New River.

Some features of this valley should be emphasized. Its existence is distinct for not less than 400 miles and, beyond central Ohio,

it deepened rapidly toward the south. It was dug in soft rocks of the Mississippian, shale, limestone or comparatively fine grained sandstone; but it headed eventually in the Archæan rocks of Canada, while an important branch rose in the Mississippian area of Michigan, covered with a cherty limestone. A gradual though probably not continuous subsidence is shown by the distribution of New River beds, which terminate one after another in progressive overlap northward until beyond the Ohio River one finds only the newest members of the formation. In like manner, overlap is distinct on the eastern or Alleghania side of the valley; at the north, the Beaver rests on Mississippian beyond termination of the New River; Hayes and others saw that, in White, Bledsoe and Cumberland counties of Tennessee, the lower members of the New River thin away in succession on the west slope of Alleghania until at last the Bonair sandstone, midway in the formation, crosses the ridge where it rests on Mississippian. A similar condition exists on the eastern side of the ridge, facing the old trough of sedimentation.

The valley was filled eventually by New River deposits. In Ohio, only the latest members appear; coarse sandstone, of which the lower portion is dense, hard and white, containing quartz pebbles from the Canadian Archæan and pebbles of fossiliferous chert from Michigan. At many places in northern Ohio, this is a mass of pebbles with hardly enough sand to bind them, while mingled with them at times are irregular pieces of shale—the whole giving unmistakable proof of river action. The chert pebbles continue almost to the Ohio River at the south, more than 400 miles from the source, the measurement being made in direct line. The upper portion contains no chert but abundance of quartz pebbles, and in Jackson and Pike of Ohio, more than 300 miles from the only possible source, those pebbles, occurring throughout the deposit, are often as large as a hen's egg. In most of Kentucky, the equivalents of these later deposits are merely coarse sandstones with layers of small pebbles,—it must be remembered that there one sees only the border, not the deeper part of the valley. In the southern part of the state the beds consist largely of "hailstone grit," for there the exposures reach beyond those at the north. Soon after passing into Tennessee,

the rocks lose coarseness and within 40 miles, according to M. R. Campbell, are no longer hard enough to affect the topography; but in that interval a new sandstone, the Bonair, belonging lower in the column, is reached: fine-grained at first, it soon becomes coarse and within a few miles it is a pebbly rock, massive, 60 to 90 feet thick and containing very little clay. The rate of fall in the original stream cannot be determined as there was differential subsidence, but some conception may be gained from the thickness of deposits. The extreme along deepest part of the valley in northern Ohio is 175 feet; in southern Ohio, 310 feet remain and the original thickness was not far from 400 feet; in southern Kentucky, it was more than 1,000 and in central Tennessee not less than 1,500. The deposits are all of river origin; there is no trace of marine conditions, except at the extreme south, nor is there any evidence of shore action; the pebbles are round, not flat: proof of selective action by running water abounds along the whole course. One has here merely a subaerial valley, filled with river deposits. The main western drainage line followed the same course until late in the Athens.[15]

Roy[16] has published some notes respecting the Sharon coal bed, the first member of the Beaver formation, which show that the closing deposits of the New River had become dry land, exposed to subaerial conditions. In the Mahoning valley that coal bed occupies serpentine, usually narrow troughs, which sometimes unite, but ordinarily are separated by long intervals of barren ground. The troughs were eroded in the old plain and the separating ridges are merely planed down knolls. In some cases, the troughs were eroded in Waverly rocks, which there are largely Devonian. The lowest coal bed in Jackson county, in the southern part of the state, is

[15] This summary is based on observations by J. S. Newberry, M. C. Read, A. W. Wheat, E. B. Andrews, A. A. Wright for Ohio; A. R. Crandall, J. Lesley, G. M. Sullivan, W. M. Linney, M. R. Campbell for Kentucky; J. M. Safford, W. Hayes, M. R. Campbell for Tennessee. These are given in "Carboniferous of the Appalachian Basin," *Bull. Geol. Soc Amer.*, Vol. 15, 1904, pp. 37–210.

[16] A. Roy, "Third Annual Report of the State Mine Inspector," Columbus, 1876, pp. 129–131.

midway in the great sandstone mass filling the valley just described. It occupies a trough in that sandstone, showing that, during migrations of the stream in its valley, portions of the flood plain remained exposed long enough to permit accumulation of an important coal bed.

A valley of notable extent existed in western Pennsylvania during the early Allegheny. There is good reason for believing that it reached as far east as the border of Cambria county, but connected observations begin only in Jefferson county, somewhat more than 40 miles farther northwest; thence the course can be followed across southern Clarion, northern Armstrong, northern and western Butler into northern Beaver,—almost to the Ohio River, a distance of about 90 miles in direct line. The interval from the Vanport limestone down to the Homewood sandstone—the last member of the Beaver—is filled with coarse to pebbly sandstone in a strip, 8 to 10 miles wide, on each side of which the normal section is exposed. To trace this valley southward along the Ohio valley is not possible, as the horizon passes quickly under cover, but there are good reasons for supposing a southward extension. Borings at Wheeling, West Virginia, on the Ohio, report the interval filled with sandstone; at Moundsville, 10 miles south, a line of borings begins, which is continuous across Wetzel county of West Virginia into Greene county of Pennsylvania, in all of which sandstone fills the interval, thus indicating the existence of a long tributary from the east. It may be that the stream's course lay well west from the Ohio, nearer that of the pre-Beaver valley and that even the top member of the Beaver was invaded. Hodge reports that in Coshocton county of Ohio, a sandstone begins at 25 feet below the Vanport limestone and continues downward 280 feet to a thin coal bed resting on the New River conglomerate, thus passing through the whole of the Beaver.[17]

The portion of the column, beginning with the Vanport lime-

[17] The observations by W. G. Platt, I. C. White, H. M. Chance, J. F. Carll and J. J. Stevenson, on which this summary is based, are recorded in "Carboniferous of the Appalachian Basin," *Bull. Geol. Soc. Amer.*, Vol. 17, 1906, pp. 65–228; J. T. Hodge, Ohio Geol. Survey, Vol. III., 1878, p. 572.

stone and extending upward for 75 feet or more, tells of stream erosions in a great area. That limestone is replaced with sandstone at many places in Pennsylvania is shown by I. C. White. Grimsley[18] has described a "washout," which he observed at New Cumberland, on the Ohio River in West Virginia. It involves the Middle Kittanning coal bed and the associated rocks. The course of the "roll" is S. 30° E. The replacing sandstone is exposed along a stream near the town, where it is 1,200 feet wide. Approaching from the west, the coal is cut off, its thick underlying clay becomes sandy and the sandstone mass becomes continuous with that below the clay. This valley was filled during deposition of the sandstone which elsewhere forms the roof of the coal bed. Within the "roll," nodular and lenticular masses of coal occur along with numerous long strings, one and a half to 3 inches thick. This cut out was traced for about 2 miles.

The same horizon is marked by stream cutting in a considerable part of the Hocking Valley coal field of Ohio. The phenomena were described first by E. B. Andrews and at a later date by Orton.[19] The latter is not inclined to believe that the work was done by streams, thinking rather that it was done by the ocean.

Illustrations of similar conditions are found abundantly in coal fields elsewhere. Ashley[20] has described the "Coxville Carboniferous river" in Parke county, Indiana, a Coal Measures valley filled with sandstone. It is 600 feet broad and the sandstone is exposed to a depth of 40 feet. On each side the sandstone spreads above the exposure and is seen resting on a coal bed. At another locality, the sandstone is 180 to 190 feet thick. At Silver Island in Fountain county and elsewhere the same features are shown at this horizon. It had been suggested that these, with some others, are parts of a drainage system, but Ashley hesitated to accept this, believing that if it were true there should be evidence of greater unconformity than has been observed. He remarks, however, that

[18] G. P. Grimsley, "Clays, Limestones and Cements," West Virginia Geol. Survey, Vol. III., 1905, pp. 215, 216.

[19] E. Orton, Ohio Geol. Survey, Vol. V., 1884, pp. 936, 937.

[20] G. H. Ashley, "The Coal Deposits of Indiana," Twenty-third Ann. Rep. Indiana Geol. Survey, 1899, pp. 272, 377, 385, 386, 552, 821, 956, 1261.

an extensive uplift in the northern part of the field would be sufficient. Channels are numerous at several horizons in Indiana and some of them seem to belong to a drainage system flowing southwest, as the smaller channels enter the larger in that direction and the larger ones increase in size. Non-conformity has been observed at many horizons in Indiana.

"Washouts" receive much attention in the British coal reports. Some are of slight extent vertically, of a type which will be considered in connection with the roof of coal beds; but there are others of serious importance, resembling those already described. Strahan[21] states that in the Ebbw valley of South Wales, the Rock Yard and Three-Quarter veins have been washed out for 1,200 yards on one property, a vertical cut of not less than 110 yards. In another valley, the Rock has been removed for about a mile. Scott[22] has described an old valley or estuary due to denudation and removal of Coal Measures beds. The earlier Coal Measures were removed and others deposited in their stead. Subsequently, some of the newer beds were removed and were replaced with others, also of Coal Measures age. Prestwich,[23] who long before Scott had discussed this "Symon Fault," recognized that it differs notably from the ordinary washouts of coal and that the Lower Coal Measures had been removed from an area of great length and breadth. The work, in his opinion, may have been done by subaerial denudation or by wasting currents. Fragments of coal and associated rocks are not uncommon in the newer deposits. Geikie[24] has given among others an illustration of contemporaneous erosion observed in the Coal Measures at Sanquhar, Scotland. Respecting all, he is compelled to the conclusion, "it is evident that the erosion took place, in a general sense, during the same period with the accumulation of the strata." De la Beche, in his "Geological

[21] A. Strahan, "Geology of the South Wales Coal Field," Part II., 1900, pp. 65, 68.

[22] M. W. T. Scott, "On the Symon Fault in the Colebrook Dale Coalfield," *Quart. Journ. Geol. Soc.*, Vol. XVII., 1861, pp. 457 et seq.

[23] J. Prestwich, "Geology of Colebrook Dale," *Trans. Geol. Soc.*, II., Vol. V., Part III.; "Geology," Vol. II., 1888, pp. 98, 99.

[24] A. Geikie, "Text Book of Geology," 3d ed., 1893, p. 506.

Observer," has discussed such occurrences in detail. Green[25] described several instances seen in the Yorkshire area. The Handsworth Rock, 40 feet of sandstone, disappearing towards north and south, fills a trough eroded in shale. The great deposit, known as the Rotherham and Harthill red rock, was deposited in a valley eroded in upturned Middle Coal Measures; and the deposition was earlier than the Permian, since the red rock underlies the magnesian limestone. The little coal basin of Commentry in France shows a striking example of contemporaneous erosion, which has been exposed in cross section by two of the great quarries. Toward the close of the period of deposit, a valley was eroded in the Coal Measures. Afterwards, this was filled by successive deposition with light-colored sands and gravels. At a somewhat later date, an eruption of igneous rock in the immediate vicinity pushed these horizontal beds into a compressed, somewhat complex synclinal and folded the older beds beyond into overturned folds, while faulting the Grande Couche, to whose roof the erosion had reached.[26] The same process of erosion was repeated in later times and a newer filled-valley has been exposed during deepening of the eastern tranchée.

Contemporaneous erosion provides evidence that the rocks underwent folding during deposition of the Coal Measures. A few notes from southwestern Pennsylvania will suffice for illustration and, no doubt, they will recall to the reader instances in other localities.[27] The Washington-Brady Bend anticline is crossed by the Monongahela River at Pittsburgh and the Claysville anticline is crossed by the Ohio River at a short distance farther west, near Woods run. These folds existed in the later part of the Cone-

[25] A. H. Green, "The Geology of the Yorkshire Coalfield," London, 1878, pp. 397, 456, 481–484.

[26] J. J. Stevenson, "The Coal Basin of Commentry in Central France," *Ann. N. Y. Acad. Sci.*, Vol. XIX., 1910, pp. 198, 199. H. Fayol has presented a very different explanation of the phenomena in "Reunion extraordinaire dans l'Allier," *Bull. Soc. Geol. France,* III., Vol. XVI., separate, pp. 35–37.

[27] Second Geol. Survey Pennsylvania, Rep. K, 1876, pp. 310, 311, 324–326; Rep. KK, 1877, p. 303.

maugh and had lifted much of the region above the area of deposition. On the latter fold, a deep railway cutting shows sandstone, 25 feet thick, resting on shales with limestone. At a few rods west, the sandstone suddenly becomes 75 feet thick, replacing the underlying beds; but, within two miles, the lower part of the sandstone disappears almost abruptly and the normal section reappears. The same sandstone was seen in another section farther north, but, in that direction, the horizon soon passes into the air while southwardly it passes almost at once under cover. The rocks on each side of this valley have a dip of 80 feet per mile, whereas that of the sandstone within is but 40 feet. The crest of the Washington axis is shown well in a railway cutting. There, the shales overlying the Ames limestone, midway in the Conemaugh, come down and replace that limestone and underlying beds to an unknown distance below the roadway; but at barely half a mile the normal section is reached. This is clearly on the crest of the fold, for the Ames limestone dips in opposite directions on the sides of the shale-filled space. On the west slope of the Salzburg anticline in Westmoreland county, near Penn station, one may see an illustration of alternating erosion and deposition, in type resembling the "Symon Fault." This is in the Monongahela formation, somewhat more than 100 feet from the bottom. At the entrance to a long railway cutting, a sandstone, 60 feet thick, rests on 6 feet of irregular sandstone, containing streaks of coal. Within a few yards, 8 feet of limestone is shown under the upper sandstone but it continues for less than 20 yards and is cut off abruptly by the sandstone. In a branch cutting, the sandstone is well exposed for a short distance but is soon replaced with yellow shale, which is very local.

Aside from the continued contraction of the area of deposition, there is little evidence of great movements within the Appalachian basin. For considerable periods of time, areas of many hundreds of square miles received no deposits; the anticlines evidently were developed slowly. The Appalachian revolution apparently spent its force during Coal Measures time mostly at the east. But in Europe the Upper Carboniferous disturbances have left more note-

worthy records. Barrois,[28] long ago, showed that the great movement in the Cantabrian area occurred between the Middle and the Upper Coal Measures. Douville had found evidence of similar conditions in the Rhine country and had concluded that the movement was general between Saxony and the Vosges. Barrois recognized the time as one of great denudation and reworking of materials, for the conglomerate of Tineo came partly from Carboniferous rocks. More recently, he has shown by stratigraphical and palæontological evidence that in the Nord basin there exist two anticlinals within rocks of the lower coal terrain.

Angular and rounded fragments of coal have been found in sandstone, shale, limestone and even in the coal itself; that such occurrences have an important bearing on hypotheses respecting the formation of coal beds has been patent to students everywhere but no systematic studies have been made by any except within very recent years. The conditions deserve careful consideration.

The earliest recorded observation, found by the writer, is that by Logan,[29] who referred to pebbles of coal and coal shale in the Pennant as though they were familiar objects. De la Beche speaks of them in the same way in his "Geological Observer." Some of the pebbles are 2 to 3 inches in diameter and exhibit the definite cleavage. Rounded pebbles of coal belonging to the lower series have been found in the upper—and it is certain that the coal, in some cases, was hard when removed, for at quarries in Swansea, *Sigillaria* stems show impressions of the pebbles. Jukes,[30] in discussing the evidence of unconformity between the Carboniferous and the Permian of South Staffordshire, finds additional proof in the pres-

[28] C. Barrois, "Recherches sur les terrains anciens des Asturies et de la Galice," *Mem. Soc. Geol. du Nord.*, Vol. 2, No. 1, pp. 599, 600; "Exposé de l'état des connaissances sur la structure géologique du bassin houiller dans le Département du Nord," Lille, 1909, p. 20.

[29] W. E. Logan, "On the Character of the Beds of Clay lying immediately below Coal Seams of South Wales," *Proc. Geol. Soc.*, Vol. III., 1840, p. 276.

[30] J. B. Jukes, "The South Staffordshire Coal-Field," 2d ed., 1859, p. 136.

ence of angular and rounded fragments of Coal Measures rocks with pebbles of coal in the lower part of the Permian.

Andrews[31] found in the lower part of a sandstone overlying the Nelsonville coal bed a rounded fragment of coal, measuring 4 by 2 inches. It bears so close resemblance to coal from Straitsville, only a few miles away, that he believed it derived from that place—the coal bed being the same at both localities. This great coal deposit is only 200 feet above the bottom of the Ohio Coal Measures. Andrews is convinced that the coal had been completely formed by the time that 12 feet of shale and one foot of sandstone had accumulated at Straitsville. He observed irregular fragments of coal, some angular, others rounded, in a sandstone within Wayne county of West Virginia.

Jordan[32] states that the Welsh Coal Measures are divisable into the Pennant Grit above, with few coal seams, and a lower division, mostly shale, with numerous coal seams. He found no coal pebbles in the lower division, but in the lower part of the Pennant they are present, associated with pebbles of granite. Logan's pebble of cannel was found in slate overlying a bed of ordinary coal and was supposed by him to have been derived from a bed, 2,000 feet lower in the series. Jordan objects that there is no evidence that the lower beds were upraised and denuded before deposition of the upper beds. He thinks that the pebbles were derived "either from the seam of coal above which they are found or from the destruction by erosion of a seam of coal, which once existed approximately in the position in which they are found, the erosion in either case being effected by the strong water courses which distributed the grains of sand and other material upon the coal seam." He refers to the "Rock Fawr" seam near Bridgend, where the sandstone roof contains a notable quantity of slightly rounded pebbles of coal, similar to those of the underlying seam. Logan's pebble, he thinks, came from a superficial layer of cannel in the Penslawdd seam. The

[31] E. B. Andrews, Ohio Geological Survey, Vol. I., Part I., 1873, pp. 355–357.

[32] H. K. Jordan, "On Coal Pebbles and their Derivation," *Quart. Journ. Geol. Soc.*, Vol. XXXIII., 1877, pp. 932, 933.

effects of a water current are seen in the Forest of Dean, where a coal seam, 5 to 6 feet thick, was washed out in one portion of the colliery and redeposited in another, where it is 8 to 12 feet thick. The character of the pebbles led him to the conclusion that the coal, prior to deposition of roof materials, "was to great extent consolidated though perhaps only partially indurated."

In discussing this paper, Moggridge stated his belief that the pebbles were derived from broken up coal beds, the debris being distributed in the newer deposits. There is a bed of good cannel only 4 miles from Penslawdd, so that one need not look far for the source, the more so since the cannel is at greater altitude. Morris thought the pebbles derived from one of three sources; they might be fragments of floating wood encased in sandstone and carbonized, they might come from the breaking up of submerged forests, whose fragments became embedded in sands and clays, or from the breaking up of coal beds. Jordan could not accept Moggridge's suggestion, because the present greater altitude of the cannel bed is due to late movements, or those of Morris because the pebbles are confined to sandstone roofs and are not distributed throughout the series.

It is well to introduce here, in advance, notes having some bearing on the matter in hand, though more upon another, which will be considered in connection with coal beds themselves. Stevenson[33] found coal fragments in a sandstone overlying the Pittsburgh coal bed. At one locality, the lower layers "contain lumps of coal, coarse pebbles and fragments of vegetable stems, the whole looking as though its deposition was accompanied by enough disturbance to tear off part of the old swamp. It is clear, however, that not all of the fragments found in the stratum belong to the same bed. Some of them are crushed and fractured in such manner as to show that they were consolidated before removal, while others are saucer-shaped." He thinks that the latter came from the Pittsburgh coal bed and that the others were derived from an older bed, outcropping at some distance eastward. At another locality, the derivation is

[33] Sec. Geol. Surv. Penn., Report K, 1876, pp. 90, 137, 285; Report KKK, 1878, pp. 79, 81, 87, 118.

local, for the upper division of the Pittsburgh has been removed and its fragments distributed in the overlying sandstone. The condition is in no wise unusual. In a later report, he says that the Homewood sandstone, the closing deposit of the Beaver, contains in its lower portion disks and pots of coal of shape such as one might expect where a soft mass has been entangled in sandstone and subjected to heavy pressure. At another locality, the sandstone contains coal fragments, some quite large, which he thinks represent a coal bed removed from the area during deposition of the coarse more or less pebbly rock. As that rock in this locality fills an old valley, it is possible that the larger fragments represent boggy material accumulated on undermined banks. In some places mentioned by this observer, the fragment-bearing sandstone rests on the uneroded Pittsburgh coal. In all probability, a sand-laden stream, sweeping across the area, removed part of the unconsolidated coal and carried it away to be deposited on an overflow surface along with living plants, as well as with the sand and hardened coal brought from a distance. The same observer mentions a locality, where the coal had been cut out and replaced with a confused mass of coal, slate and sandstone. I. C. White[34] has recorded several instances similar to the last, in widely separated localities, where the coal has been replaced with a conglomerate of worn and rounded pieces of limestone, coal, slate, and sandstone.

"Washouts" similarly filled have been reported by other observers in Pennsylvania and elsewhere. The conditions are precisely such as one can see in the streams now flowing across the bituminous field and the conclusion is the same in both cases—that the stream flows across the outcrops of rocks whose fragments are in its bed or in the "bottom" deposit of its banks. The Banc des Chavais in the Grande Couche of Commentry belongs to this type.

Renault[35] studied very carefully the coal pebbles found in the sandstones of the Commentry coal basin. Some resemble freshly

[34] I. C. White, Second Geol. Surv. Penn., Report Q, 1878, pp. 114, 268; Report Q2, 1879, pp. 270, 274–276; Report Q3, 1880, p. 176.

[35] B. Renault, "Quatrième note pour servir a l'histoire de la formation de la houille," *Comptes Rendus,* Vol. 99, 1884, p. 201.

broken coal, but others are pebbles with the angles rounded. Their coal differs from that of the beds in that it is less compact, absorbs water, has less brilliant fracture and can be cut more readily. It has the alternate bright and dull laminæ of ordinary coal. Apparently, the conversion was not complete when the fragments were torn away and the interrupted process was not renewed. He concludes that, during formation of the Commentry coal terrain, there were frequent erosions of the earlier beds of coal, clay and limestone; that those beds do not belong, as might be imagined, to a much older coal period; that the coal, found as pebbles, is, so to speak, less advanced, offering some properties differing from those of plant materials fully converted in place; that the time required for conversion of vegetable matter into coal, though very long, appears not to be excessive, since a coal basin of moderate size already possessed some coal, while the deposits were increasing. There can be no doubt respecting Renault's conclusion as to the source. No rocks older than Middle Coal Measures are known to exist in this basin of barely 12 square miles, which is divided by the broad dejection cone of Montassiégé, which contains no coal.

Fayol's[36] observations, recorded in his original work as well as in the résumé published in 1890, are of no slight importance in this connection. Pebbles of coal, angular or rounded, in all shapes and varying in size from mere grains to 4 decimeters, occur in all parts of the terrain within the Commentry basin. They are rare in the conglomerates but abound in the medium-grained sandstones of both les Pegauds and les Ferrieres, the coal-yielding divisions separated by the barren Montassiégé area. They are associated frequently with grains and pebbles of carbonaceous shale. The character of coal in the pebbles varies. Those in the older part of the formation are anthracite, like the adjacent coals; those in les Ferrieres are meager, as is the coal of that area; while those of les Pegauds are of flaming coal like that from the Grande Couche. So that the coals of the pebbles are like those of the immediate area. At the same time, it is all-important to note that, according to Fayol,

[36] H. Fayol, "Études sur le terrain houiller de Commentry," livre premier, *Bull. Soc. Ind. Min.*, 2me Ser., Vol. XV., 1887, pp. 140, 141.

pebbles of anthracite have been obtained near the Grande Couche and that in some pebbles the coal has the appearance as well as the composition of lignite. But these last are exceptional—they, evidently, are of the type studied by Renault. The distribution of the pebbles is absolute proof that, before the Gres Noirs coal bed was formed in its present area, not only the older rocks with anthracite, but also the Grande Couche itself and its associated beds were exposed to subaerial streams, by which the pebbles of coal and carbonaceous shale were rounded. The writer collected many of these pebbles from a sandstone at less than 60 feet above the Grande Couche.

Barrois[37] says that pebbles of coal are less numerous in the paralic basins of north France than in the limnic basins of the plateau, but he had opportunity to study some which had been discovered recently. Geologists, in the majority of cases, have believed that coal pebbles had travelled for only short distances and that they prove the process of conversion far advanced when the fragments were detached; but some, objecting to such rapidity of conversion, have preferred to believe that the fragments, when entombed, were merely rolled vegetable matter. He notes the statement respecting the Commentry pebbles, that some, at least, show contraction, evidence that the conversion was not complete. The marshes of the Pas-de-Calais, attacked by tides, give off blocks of peat, which become rounded and at length ellipsoidal. E. Geinitz has made a similar observation on the Baltic shore near Rostock. The Bruay pebbles occur in hard coarse sandstone, are from mere grains to 14 by 5 by 3 centimeters. They are chiefly cannel, at times have laminæ of brilliant coal and, under the microscope, they show vegetable structure—they recall the peat pebbles of the Pas-de-Calais. They have suffered contraction, for they are surrounded by a film of calcite which penetrates the pebbles in veinules.

As the result of his studies, Barrois has found that coal pebbles usually occur in coarse sandstones above coal beds; that they have

[37] C. Barrois, "Observations sur les galets de Cannel-coal du terrain houiller de Bruay," *Ann. Soc. Géol. du Nord.*, Vol. 37, 1908, pp. 3 et seq.

the coal of the area, not differing materially in volatile content; that they belong to some coal bed not far away, for one never finds maigre pebbles in a gras area, or the reverse; that pebbles of cannel occur more frequently than those of ordinary coal. These conditions hardly justify the supposition that the pebbles were brought by streams flowing over beds, which, already coal, alternated with shale and sandstone. The Bruay pebbles are all from one coal bed and that must have been near by. The presence of laminæ of brilliant coal in the sandstone, identical with the laminæ in the cannel, leads to the same conclusion, because in the Nord basin, as in South Wales, cannel is in the roof of the beds. When a coal bed is eroded, the cannel is the first portion to be removed, which explains the frequent occurrence of cannel pebbles in areas where that type of coal is rare. Barrois concludes that the Bruay pebbles came from one bed, in which the material was not wholly converted. The erosion occurred simultaneously over an extensive area and was due to changes in course of a stream, loaded with sediment, which inundated the bog abruptly. It must have come from a distance, for the deposit contains elements of crystalline rocks, larger and more abundant than in any other clastic deposit within the basin.

Petrascheck[38] investigated the mode of occurrence of coal pebbles in a sandstone within the Galician area. The deposit is thick, usually only moderately coarse, but in the portion carrying the pebbles it becomes irregular and conglomerate. Some fragments of coal are distinctly rolled, some have merely rounded angles, while others have the edges sharp. The minutely pitted surface of some fragments led him, at first, to imagine that they had been peat when entombed, the pitting being due to pressure by sand grains. But the conditions throughout compelled him to abandon this conception. The form and substance of the pebbles favored belief that at the time of burial the material was already hard. Glance coal breaks into angular pieces and can endure little chafing, while cannel and

[38] W. Petrascheck, "Das Vorkommen von Steinkohlengerollen in einem Karbonsandstein Galiziens," *Verhandl. k. k. Geol. Reichsant.*, 1909, Wien, 1910, pp. 380 et seq.

carbonaceous shale are rounded easily. The contrasts are shown well by fragments in this sandstone, for the glance coal is angular and the cannel rounded. Fragments of slaty coal also are rounded, but the shale portion resisted better than the coal portion and the fragments are flatter than those of cannel. The bond between coal and shale must have been, at entombment, such as is seen in slaty coal now. It might be supposed that the pebbles are buried fragments of wood; but such complete penetration of wood by shale is inconceivable; there would be, moreover, so great change in volume that the fragments could not retain their form. He is convinced that the consistency of glance on the one hand and of cannel on the other is so different as to make certain that the materials had acquired their characteristics before burial. The source of the pebbles cannot be ascertained, but they do not appear to have come from any contiguous bed, and the only suggestion possible seems to be that they have been derived from much older deposits. The features of the rock carrying the coal pebbles, especially its coarseness, in which it differs from the sandstone on each side, seem to suggest that it may occupy a valley eroded in the sandstone.

Coal pebbles are not confined to the Coal Measures. Haast[39] found them in Cretaceous sandstone of northern New Zealand and Hutton found them abundant in a conglomerate of the same age in Otago, where the rock rests on the eroded surface of a coal bed. Fragments of coal have been reported by the writer from upper Cretaceous sandstones of New Mexico and a large block of oolite coal was obtained in the chalk of Kent, England. A more curious phenomenon is the existence of apparently rolled pebbles in the coal itself. Gothan[40] states that in the Lias area of Fünfkirchen, Hungary, there is, near Vasas, abundance of "Mugelkohlen," round to ellipsoidal fragments of pure coal, embedded in almost all of the coal beds. In size they vary from nut to two fifths of a meter;

[39] J. Haast, "Report on the Geology of the Malvern Hills, Canterbury," Geol. Surv. New Zealand, 1872, pp. 50, 52, F. Hutton, "Report on the Geology and Gold Fields of Otago," Dunedin, 1875, p. 106.

[40] W. Gothan, "Untersuchungen über die Entstehung der Lias-Steinkohlenflöze bei Fünfkirchen (Pecs, Ungarn)," *Sitzungber. d. k. preus. Akad.*, Vol. VIII., 1910, pp. 136–143.

the surface is smooth, metallic and lustrous, often with a scale-like coating such as one sees on concretions. They are separated easily from the surrounding coal, to which they are not related, and they do not occur in the associated rocks. Gothan considers the various suggestions offered to explain the occurrence of these nodules, but finds them either insufficient or not in accord with the conditions. He seems to be convinced that they are pebbles, owing their rounded form to attrition. The Geological Survey collection at Berlin contains similar forms from a mine in the upper Silesian Carboniferous, where the pebbles of coal are associated with others of quartzite, granulite, etc. There and at other localities the association is evidence of transport, but, at Vasas, rock pebbles are unknown. Gothan sees no reason to suppose that they came from a distance. He conceives that they may have been formed even while the Jurassic Waldmoor existed and that wind-moved water may have detached pieces of the harder peat. The more resistant portions of those pieces would be rubbed against each other until rounded and eventually they would sink into the peaty mud. These "balls" occur elsewhere. Hughes found[41] balls of very pure coal enclosed in coal beds in India and Stainier reports that at Turon in Asturia there is a bed formed wholly of rolled pebbles of coal; he mentions two localities in Australia, where coal pebbles are embedded in coal of notably different composition and states that such pebbles occur in the coal basins of Mons and Charleroi, Belgium.

These citations suffice to illustrate the varying conditions in which coal pebbles or fragments occur in clastic rocks or even in coal beds themselves. Gothan's explanation for existence of balls in coal may account for origin of the material. A broad stream meandering through a deep bog might easily tear off small fragments, as supposed by him, but even then the necessity for transport remains, since there could be no sufficient chafing in quiet or gently moving water. In all other cases, the transportation is clear.

[41] T. Hughes, "The Jherria Coalfield," Mem. Geol. Surv. India, Vol. V., pp. 254–256; X. Stainier, "Des rapports entre la composition des charbons et leurs conditions de gisement," *Ann. des Mines de Belgique,* Vol. V., 1900, pp. 95–97.

In some instances, the distance was small or the detached pieces were enveloped in sands and swept along as part of the mass to the place of deposition. This was evidently the condition where one finds irregular chunks and petty lentils of coal as in the sandstones of western Pennsylvania and at many places in other coal fields. These masses, torn off by a sand-laden stream, were transported without material attrition and were deposited where the speed slackened on an overflow surface. It must be noted that one rarely finds such masses in localities where the underlying coal bed shows evidence of erosion; very often the sandstone with coal fragments rests on an uneroded coal bed; while in very many cases the sandstone resting on a bed with channeled top is wholly without noteworthy fragments. The channel was dug in the vegetable material and was filled with sand of later arrival. It is difficult to conceive how material torn from a bed could be deposited over or very near the place of origin, unless one imagine a whirlpool of modest area; but it is easy to understand how a sand-laden stream flowing irregularly across a plain, covered with a thin marsh, could remove the cover and deposit it elsewhere. That condition is approached in considerable areas by streams like those of the Paraguayan region, where the channels are aggraded quickly in flood time and the turbid waters are driven to seek new courses.

But if the coal fragments be rounded, they point to conditions wholly different from those just considered. In the summary of observations given above, there are references to the process of conversion and to the time required for its completion. Those topics lie, for the most part, outside of the question in hand and are related to it only incidentally; but the structure and composition of coal in the pebbles make certain that it was already well advanced in conversion when removed from the bed. The Commentry pebbles in some cases were already anthracite while others, those from the Grande Couche, were still flaming coal; for both types are found in the same sandstone—that above the Grande Couche—and, along with them, are thoroughly rounded pebbles of carbonaceous shale.

In not a few localities the pebbles are cannel and they have been

regarded as derived from the cannel bench of an underlying bed. That cannel pebbles should retain their shape and size better than those of glance coal is normal, because cannel is tough and glance is brittle; but there is no reason to suppose that sapropelic muds became hard and resistant with great speed while the underlying felted peaty materials became compacted slowly. It would seem more probable that cannel pebbles are more numerous because cannel survived the shocks of transport and the glance coal was reduced to minute grains. The evidence that the pebbles have undergone much change since entombment seems to be slight and of hardly material importance. The writer, during a second visit to Commentry in 1910, examined very closely more than 100 coal pebbles scattered through the sandstone up to 60 feet above the Grande Couche. In only two, possibly three, was there appearance of contraction. Almost without exception, the pebbles were coated by a thin film of clay, such as commonly covers, in whole or in part, coal fragments on beds of actual streams in the Appalachian basin. This mud-coat, by drying, might leave a space in which a film of calcite could be deposited; but, aided by strong pocket-glass, the writer could find no evidence of contraction in the pebbles. There had certainly been no change after the sandstone was compacted. Fracture planes are rarely seen but, in very many pebbles, the typical cleavage is distinct. The pebbles of shale are not clay balls; they are fragments of laminated shale. In any event, the form of the pebbles, shale and coal alike, is that due to stream transport. Some indeed are flattened like coast shingle, but that is due merely to the original form, a block with laminated structure. Every feature of these pebbles appears abundantly on the beds of streams flowing across the Pittsburgh coal area of southwestern Pennsylvania. They leave no possible room for doubt that the coal fragments, like those of sandstone and shale, were deposited by streams flowing over outcrops of coal, shale and sandstone.

In the larger areas, pebbles are not distributed indiscriminately throughout the mass of sandstone or shale; they are localized. Petrascheck's descriptions as well as those of the Silesian area by Gothan recall the conditions observed in western Pennsylvania but

they seem to be in channels within sandstone, whereas those of Pennsylvania are channels within coal beds. The coal pebbles in the latter localities could not have come from the enclosing coal; all of them, coal, sandstone, shale, limestone, are rounded as by stream transport and the rounding is such that they must have been brought from a considerable distance. Everything about these pebbles of coal indicates that, during much of Coal Measures time, a considerable part of the area of deposition was land, showing outcrops of the various types of Carboniferous deposits, whence flowing streams gathered their loads of detritus. With varying conditions, streams shifted their courses or washed down the materials accumulated on their beds to fill the lower reaches of their channelways.

The phenomena of non-conformity and of contemporaneous erosion compose a body of evidence that throughout the Pennsylvanian the progress of events was like that in previous and in succeeding periods of the world's history; there were foldings of the crust, there were differential elevations and subsidences and at all times much of the region was exposed to subaerial erosion.

The Distribution of Sedimentary Rocks.

The Coal Measures rocks are sandstones, shales, limestones and coals, the terms being employed in the broad sense. All occur in each of the great eras and limestone seems to be wanting in only the Pocahontas or earliest stage of the Pottsville. An understanding of the geographical distribution and structural variations of these rocks should give some insight into the conditions prevailing at the time of their deposition; but determination cannot be complete, as erosion has removed the beds from a broad strip on the eastern border between the anthracite fields of Pennsylvania at the north and the Alabama line at the south. Beyond the latter, one finds on the eastern side only Pottsville beds; later formations are unrepresented; it is more than possible that they never were represented.

Pocahontas deposits occupied an area on the eastern side, very narrow at first but widening gradually toward the west until the close of the stage, attaining the greatest width near the Tennessee-Virginia

line. Whether or not they extended across Tennessee into Alabama cannot be determined by the stratigrapher, the palæobotanist must answer the question; but one can hardly resist the *a priori* conclusion, whatever that may be worth, that the Pocahontas did extend across Alabama and around to the southwestern outlet, as no outlet westward for the waters of the eastern valley appears in Virginia and Tennessee, and there seems to be not the slightest reason for supposing an eastern outlet anywhere to the Atlantic. The New River area is much greater, embracing the southern and middle anthracite fields at the north, where the western limit is well defined. In the bituminous region, the eastern outcrop is continuous from the northern limit in West Virginia into Alabama, where the formation is recognizable throughout the whole field; northward, on the westerly side of Alleghania, it occupies a broad area to the northern border of Kentucky whence it extends in a narrow strip almost to Lake Erie. The Beaver, at its close, evidently covered the whole basin from the northern border southward to central Tennessee; beyond that line it has been removed by erosion for about 75 miles and it is not reached again until one is well south from the northern line of Alabama. The stratigrapher cannot make correlation of horizons there, but the presence of Beaver seems established beyond doubt.

The formations of the Athens are recognizable in the anthracite fields as well as throughout the bituminous region southward into Kentucky and West Virginia; how extensively they were represented in Tennessee is undetermined. The Wheeling and Dunkard deposits, of less original extent and confined to the northern part of the bituminous region, can be studied not only by means of the many recorded exposed sections, but also by means of many hundreds of oil-well records, which make clear the conditions as they existed in the deeper portions of the region.

The Sandstones.—Stratigraphers have asserted many times that sandstones are of very little worth as horizons. It is true that those deposits exhibit abrupt changes in structure and composition, both laterally and vertically; and it is equally true that, in not a few

cases, sandstones, due to filling of valleys and occupying restricted areas, may be misleading. Yet examination of broad areas proves that many sandstones are of great geographical extent, though often interrupted and sometimes assuming the form of immense lentils embedded in shale. In a general way, one may consider the variations as alike in all; at one locality, the mass may be fine, coarse or even pebbly to conglomerate in its different layers; at another, it may be wholly fine, coarse or pebbly; while at a third, it may be represented by more or less argillaceous shale. It may be massive, irregularly bedded or shaly and the change in structure or composition may be abrupt or almost imperceptible. There would appear to be no system in these variations; yet it may prove worth the pains to seek some explanation of the conditions, for though the quest may fail of complete success, one is likely to gather suggestions by the way, which may prove of service in other directions. Four sandstones have been selected for study: Bonair of the New River, Homewood of the Beaver, Pittsburgh of the Monongahela and Waynesburg of the Washington. But in considering these, one must make comparison with others.

The Bonair sandstone of M. R. Campbell, midway in the New River formation, can be followed from its northern termination in West Virginia, along the eastern outcrop, and from northern Tennessee, on the western, almost continuously into the southeastern basins of Alabama. The eastern and western prongs on the sides of Alleghania unite across that old ridge in central Tennessee, whence the rock spreads as a sheet throughout the coal area of southern Tennessee and of Alabama. The northern limit on the western side, in the Ohio basin of Schuchert, is very near the northern line of Tennessee where it is without pebbles; but within less than 20 miles southward it becomes notably a pebble rock; at 12 miles east from the latter place it is described as 55 feet of "conglomerate and sand stone" and a similar description is given for a section at 25 miles south from the last; but at 25 miles south-southwest, the Bonair is a mass of conglomerate with shale, and the rock is still coarser at a few miles southeast, on the eastern outcrop near the Alabama line. At a few places, the western outcrop swings several miles toward the west, approaching the border of deposit, and shows another type

of change. In Putnam county, the sandstone is very thin, with an unusual thickness of shale above and below it, the greater part of the mass having been replaced with shale; in Warren county, pebbles seem to be wanting and the rock is merely a cross-bedded sandstone. Where the mass passes under cover on the east side of this area, it is much less coarse than along the outcrop line.[42]

On the eastern side of the coal area in Tennessee, the Bonair is largely pebble rock near the Alabama line, but at 20 miles north, it is sandstone, 65 to 75 feet thick, and this is its character for several miles. But, at 32 miles from the Alabama line, it is a mass of "conglomerate and massive sandstone," a condition prevailing northward at all exposures for about 30 miles; but, thence until near the Virginia line, the sections show only sandstone with some shale, there being apparently no pebble rock. The outcrop on this side trends considerably east of north, so that, near the Virginia line, one is 75 miles away from the western outcrop; yet the rock is without pebbles, whereas on the western side, in the Ohio basin, it is coarse and pebbly. The probable equivalent in southwest Virginia is for the most part loosely cemented sandstone with shale, changing to shaly sandstone toward the west but becoming a great sandstone with some pebbles at a few miles farther along the extreme easterly outcrop. Beyond New River in West Virginia, the Bonair horizon has been recognized for about 40 miles; ordinarily the rock is merely a sandstone, but, toward the northern termination, the outcrop is carried eastward and, at the extreme exposure, one finds the rock very coarse with quartz pebbles abundant and at times with diameter of 2 inches. Westwardly it decreases rapidly and within a few miles thins out against the slope of Alleghania.[43]

Returning to the south and going southeastwardly in Alabama, one finds striking changes in the Bonair. In that state are several troughs, separated by narrow intervals and lying southeast from the continuous area, followed thus far, while that area extends unbroken

[42] This summary is based on observations by J. M. Safford, C. W. Hayes, M. R. Campbell, recorded in "Carboniferous of the Appalachian Basin," *Bull. Geol. Soc. Amer.*, Vol. 15, 1904, pp. 114–126, 136–146.

[43] For the observations of Campbell, Hayes, F. H. Bradley, Safford, I. C. White and Stevenson, see *Bull. Geol. Soc. Amer.*, as above, pp. 136–190.

into the Warrior coal field. Raccoon mountain, a prong from the continuous area, shows on its westerly side the Bonair sandstone, 30 to 50 feet thick and in great part pebbly; but on the easterly side the thickness is 75 to 80 feet and the rock is almost wholly pebbles. On Blount mountain, the southern prolongation of the east side of Raccoon, the mass thickens southwardly along the strike to 100 and finally, as estimated, to 500 feet. It is not pebbly throughout, but in portions where conglomerate prevails, the pebbles are not cemented firmly. In the small Lookout area, the Bonair is 50 to 60 feet thick and very coarse near the Georgia line, but at 10 miles southwardly it is a moderately coarse sandstone. The Cahaba basin is only a short distance southeast from the strike-line of the Lookout, but the interval sufficed for great change and the Bonair horizon is marked by more than 600 feet of conglomerate, sandstone and gritty shales; while in the Coosa field, only a few miles farther southeast, the rock is coarse conglomerate about 500 feet thick. The Lookout area, at the Tennessee line, is barely 30 miles from the present border of Archæan and the Coosa area is several miles nearer. The latter is not more than 30 miles from Raccoon mountain in direction of dip. The rock is coarsest in Coosa, less so in Cahaba, less in Blount and still less in Raccoon; in the Warrior basin beyond, one finds the Bonair persistent almost to the western boundary of Alabama, but losing its coarseness and at length replaced more or less with shale.[44]

Certain features of the Bonair should be emphasized. Where the western border of its area is approached in Alabama and at a few localities in central and northern Tennessee, the rock is less thick, with few pebbles, a more or less cross-bedded sandstone, at times replaced in part with shale. Along the western outcrop in Tennessee, aside from the extreme western localities, the rock consists, in considerable spaces, very largely of pebbles, while in other and intervening considerable spaces, it is merely a sandstone with layers of pebbly rock varying in number and thickness in different localities. And this condition exists where the Bonair passes under cover toward the east, as also where the equivalent area is cut by

[44] For the observations by H. McCalley, A. M. Gibson, Safford, Hayes and J. Squire, see as above, pp. 126–136.

the outcrop farther south. But where the horizon is exposed on the eastern outcrop near the Alabama line, and thence northward for miles the rock is pebbly with layers of conglomerate: while farther north, for an equally long distance, the rock is sandstone, rarely containing conglomerate layers but not unfrequently layers of shale. It must be noted that spaces in which conglomerate features prevail throughout the mass appear, from the descriptions, to be narrow and that bands of conglomerate pass out from them into the sandstone on both sides. At times the conglomerate is as a lentil in the sandstone. The features are the same in the southeastern basins of Alabama, for there the conglomerate shows vertical as well as horizontal passage into finer material.

The other great sandstones of the New River show similar variations, but conditions in successive beds are rarely the same in any locality. The Etna sandstone, below the Bonair, can be recognized in an almost equally great area; it varies in texture as does the upper sandstone; but it is often comparatively fine-grained and without pebbles where the Bonair is very coarse, and very coarse where the Bonair is not coarse. The sandstones were formed after the same manner, though the local conditions varied.

The Homewood sandstone of I. C. White is the closing deposit of the Pottsville, apparently the first bed to cover the whole extent of Alleghania. It was recognized in the anthracite fields by its lithological character and the identification was made complete by D. White's study of the plants, which proves that it underlies the first beds carrying an Allegheny flora. It can be followed in the bituminous region from northwestern Pennsylvania into northern Tennessee, beyond which to central Alabama it has been removed by erosion. Its equivalent in Alabama has not been determined.

The Homewood is, for the most part, a coarse conglomerate in the southern and middle anthracite fields, becoming less coarse in the latter, but even there containing pebbles up to the size of a hen's egg. The coarseness decreases in the northern field and at the easterly end the deposit is a sandstone with layers of "pea conglomerate." The small Broad Top area, which may be regarded as on the line of strike with the northern field, shows only a moderately coarse sandstone with occasional pebbles, rarely one half inch in diameter.

Some insignificant fragments, containing a score or two of square miles, remain, at the northwest, between the northern field and the bituminous region. In those, the rock is for the most part a massive conglomerate, with occasional fragments as large as a walnut, but there is little of fine material, showing marked selection by the depositing agent. Along the Allegheny front, the Homewood is by no means a coarse rock at the north in Clinton but in Center, the next county south, it has one part exceedingly coarse, with mostly quartz pebbles, at times as large as a hen's egg. In Blair, no pebbles are reported but in Bedford there are some pebbly layers; thence southward to the Potomac, it seems to be merely a massive sandstone. The only unexpected feature here is the presence of large pebbles in Center county.

This sandstone is exposed frequently in a strip, 75 miles wide, west from the Allegheny crest. On the northern border in Bradford county, it contains occasional layers of pea conglomerate, but those disappear quickly toward the west so that pebbles are few in the adjoining county. Southward to the Conemaugh River, half way to the southern boundary of the state, there is at most localities only sandstone, sometimes broken by shales; but in Clearfield county, midway in this strip, and just west from the Center county area, very coarse rock is reported at this horizon, there being layers of conglomerate with quartz pebbles often as large as a hen's egg. The deposit is in an irregular narrow space, extending half way across the county and the coarse material is wanting on the western border. This marks the eroded crest of Alleghania and the Homewood rests on what seems to be the Logan or lowest deposit of the Mississippian. South from the Conemaugh, the Homewood is variable; at one locality it has 70 feet of sandstone while at 4 miles away the interval is filled almost wholly by shale. But for the most part, from the Conemaugh to the Baltimore and Ohio railroad in West Virginia, the rock is a moderately coarse sandstone with occasional pebbles, seldom larger than a pea.

Farther west in Pennsylvania, the Homewood is sandstone at all localities along the northern border, varying in thickness from 15 to 70 feet at expense of underlying beds. Pebbly layers occur at times but the pebbles are small; southward, in Clarion and

Venango, it is coarse to somewhat pebbly sandstone at some localities but shaly at others; there, as in northern Butler, it varies from 15 to 80 feet, always at expense of underlying beds. In Mercer it is from 70 to 30 feet, being thickest at the north where it varies from good building stone to pebbly rock, while farther south in Lawrence the horizon is marked by shale to coarse pebbly rock, but in most of the county it seems to be represented by fine material. This is within the drift covered area and the exposures are not sufficient for determining the relations of the pebbly areas.[45]

The change beginning in western Pennsylvania becomes very marked in Ohio. Along the northern and western outcrop the deposit is wholly indefinite, being mostly shale, sandy to argillaceous, with occasionally some shaly sandstone. So great is the contrast between these and the eastern conditions, that for a generation the relations between the Ohio and the Pennsylvania Measures were ground for very serious dispute. The Homewood is nowhere in Ohio an important member of the section. In Kentucky the interval is filled with characterless shale and sandstone. In northern Tennessee, the section extends to and above the Homewood horizon and without doubt one of the important sandstones is equivalent to the Homewood. On the eastern side in Virginia and West Virginia, the horizon is distinct, though at some localities, north from New River in the latter state, one cannot differentiate the Homewood from underlying beds. But the rock underlying the Allegheny flora is usually a well-marked sandstone for at least 40 miles north from that river; there, however, the outcrop turns toward the east and the rock becomes pebbly. In Tucker county, the last eastward exposure shows 55 feet of rock, the lower portion for 40 feet being massive conglomerate. Westwardly from the outcrop, the rock rapidly becomes less coarse and, within a score of miles, it is shaly sandstone or shale.

The Homewood is buried deeply in the greater part of West Virginia, north from the Kanawha River, as well as in eastern Ohio

[45] The observations by F. Platt, W. G. Platt, I. C. White, H. M. Chance, E. V. d'Invilliers and Stevenson are recorded in "Carboniferous of the Appalachian Basin," as above, pp. 42–70. The reader will find an admirable summary of earlier observations by H. D. Rogers, J. D. Whelpley, R. M. S. Jackson, P. W. Shaeffer and J. P. Lesley in H. D. Rogers's "The Geology of Pennsylvania," 1858, Vol. II., pp. 21–26.

and southwestern Pennsylvania. For that area one can depend only on the series of oil-well records, chiefly those collected and collated by I. C. White. Where exposed along the eastern and southern border in West Virginia, the horizon is marked usually by a sandstone, seldom very coarse and sometimes shaly. In the interior or deep part of the basin, where the coal beds are indefinite, it is not always easy to carry the section, though the drillers find no difficulty in identifying the horizon. At the north, in the "Panhandle," the Homewood seems to be represented in most cases by shale, sandstone occurring, for the most part, as filling valleys. So also in Washington of Pennsylvania and Wetzel of West Virginia the interval is frequently filled with shale. The horizon is indefinite throughout; in many records it is marked by sandstone, in many others by shale. There is no room for doubt that, in considerable spaces, sandy shale was consolidated into sandstone; but careful tabulation has convinced the writer that, in not a few of the long lines of records reporting sandstone, one has merely the records of subaerial valleys eroded not long before or after the close of the Beaver.

The Homewood material came from all sides of the basin. On the eastern side, the quartz pebbles from the old Appalachian land decrease rapidly in size westward; the strip of coarse rock in Center and Clearfield counties of Pennsylvania with possibly related patches in Jefferson and Elk counties as well as a similar strip near the northern outcrop may be records of valleys heading east from the present Allegheny front. The materials at the west came clearly from the low slopes of Cincinnatia and from the north. The very marked variations in thickness, always at the expense of underlying beds, leads one to suppose that the irregular crustal movements, so characteristic of the Allegheny, had already begun.

The Allegheny was a time of great irregularity of deposition, there being abundant evidence of subaerial erosion at many places and at different horizons; and the old valleys have been filled, in most instances, with more or less pebbly sandstone. At the southeast the formation is marked by coarse massive sandstones extending into the Conemaugh, which cross West Virginia in southwest direction; but they lose their coarseness quickly toward the northwest. The sandstones of this formation as well as those of the Conemaugh

become less important in Ohio, where occasionally they contain some small pebbles.

The Pittsburgh sandstone of H. D. Rogers, the first great inorganic deposit of the Monongahela, is separated from the underlying Pittsburgh coal bed by a shale varying much in thickness—often wanting. The distribution and characteristics of this sandstone show that great changes had taken place since the close of the Beaver, even since the close of the Allegheny. The area as it now exists is restricted to the southwest corner of Pennsylvania, a narrow strip of eastern Ohio and north central West Virginia. Outliers in synclinals at the east as far as the Potomac area of Maryland and West Virginia may be regarded as evidence that the eastern border of the deposit was not more than 75 miles west from the Archæan of Appalachia.

The horizon is marked by shaly sandstone and sandy shale in the outliers, but when one, going westward, reaches the continuous area in Westmoreland and Fayette of Pennsylvania, he finds commonly a hard massive sandstone, occasionally changing into shaly sandstone. I. C. White has followed this in West Virginia to the Kanawha River and thence along the southern outcrop into Ohio. There, as in Pennsylvania, the rock is often coarse, at times forms cliffs, is feldspathic, seldom pebbly, except at the southwest, and the pebbles are always small. Within little more than a score of miles from the eastern outcrop this rock disappears, permitting, in southern Pennsylvania and adjacent part of West Virginia, the Redstone limestone to rest on the shale overlying the Pittsburgh coal. The change is very abrupt. At Morgantown, West Virginia, this sandstone, 40 feet thick on the east side of the Monongahela River, is absent on the west side and its interval has disappeared from the section. In Pennsylvania, this sandstone extends southwardly from the northern outcrop 60 or 70 miles but it thins westwardly so that in the West Virginia "Panhandle" it is absent. Its continuity along the northern outcrop is broken and a gap of perhaps 25 miles is in the panhandle and Jefferson county of Ohio, but the rock reappears in Harrison county of the latter state, where it is 40 to 70 feet thick. Thence it has been followed to southern Ohio, where it is continuous with the southern border as determined by I. C. White in West Virginia.

Whether or not the sandstone existed in the northern area, where no trace remains, cannot be determined. Erosion has removed the whole section in the space where the sandstone should be present; but it seems probable that the sandstone was not wholly continuous, as an outlying exposure in Jefferson county of Ohio shows only shale. Aside from this gap at the northwest, the sandstone is practically continuous around the whole Monongahela area; it is often coarse, sometimes shaly, at others massive, is seldom pebbly, except at the southwest, where it has conglomerate layers with pebbles up to an inch in diameter; occasionally it is replaced with sandy, even argillaceous shale. It thins away rapidly toward the center of the area; well records in the deeper part of West Virginia frequently note sandy shale or sandstone, just above the Pittsburgh coal bed, but, in view of the disappearance of the deposit at the border of the area, these occurrences cannot be taken as its equivalent.

The material came from all sides of the basin, as is clear from the distribution, but on the western and southwestern outcrop the rock is coarse, at times even conglomerate, whereas the earlier sandstones are fine grained. If the conglomeratic sandstones at top of the New River were exposed to erosion at this time, one would have no difficulty in determining the source of the material. That those sandstones were exposed appears the more probable when one considers that the area of deposition had become greatly restricted. The coarse rocks of the Logan in southern Ohio, long exposed, may have yielded some of the material, but Hyde's description of those deposits makes clear that they were not the source of the larger pebbles. The character of the material along the eastern outcrop suggests that it had come from a distance and had been rehandled many times.

The higher sandstones of the Monongahela in Pennsylvania are mostly of small areal extent and are present for the most part on the borders of the Monongahela area; but in West Virginia they are thicker and more extended. Yet there as in Pennsylvania they decrease toward the center of the area and are replaced with finer deposits.

The Waynesburg sandstone, separated by a thin deposit of shale

from the underlying Waynesburg coal bed, is the first important member of the Washington formation.

This sandstone was not seen in the Broad Top basin of Pennsylvania but it is present and 45 feet thick in the Potomac region of western Maryland. The horizon is not reached in other outlying patches of the higher coals and only occasional fragments remain on the extreme east side of the continuous Washington area. These, separated by intervals of several miles, consist of coarse sandstone containing pebbles of small size, scattered irregularly throughout the mass. At six or eight miles farther west, the rock is continuous. At the northern outcrop it is from 25 to 50 feet thick, consisting of sandy shale to laminated sometimes massive sandstone; thence to the West Virginia line the same character persists, though the lower part tends to become massive and the thickness increases at times to 75 feet, but not at expense of underlying deposits. Oil well records show that in the extreme southwest corner of Pennsylvania this "Bluff Sand" of the drillers persists with thickness of 55 to 65 feet. Westwardly into the West Virginia panhandle the deposit is somewhat thinner, less well consolidated, while the lower portion occasionally contains pebbly layers. Southwardly in West Virginia, I. C. White has followed the Waynesburg sandstone along the eastern and southern outcrop into Ohio. It is 50 to 75 feet thick and for long distances forms rugged cliffs. At the southeast, on the Pocatalico River, he found it massive, very coarse and pebbly. In the interior of West Virginia, this sandstone is persistent in all well records southward to some distance beyond the Baltimore and Ohio main line and westward to the middle line of Doddridge and Wetzel counties. Farther west, it is seldom enough consolidated to be called "sandstone" in the drillers' record. Farther south, the records can hardly be compared; typical horizons are lacking in a considerable area and the region is marked by notable irregularity in intervals.

Following the northern border, one finds this sandstone 50 feet thick in Jefferson, Harrison and Belmont counties of Ohio and it is persistent thence along the western outcrop. In Morgan county it contains layers of pebble rock; in western Washington it is 50 feet of sandstone with no pebbles reported, while in the southeastern

part of that county a massive pebble rock extends at times to almost 100 feet above the Waynesburg coal bed. Within the oil region of the same county the Waynesburg is represented by 28 feet of pebble-rock. In Athens and Meigs it is a coarse sandstone, at times a pebble-rock in the latter county, where it becomes continuous with the southern outcrop in West Virginia.

The Waynesburg sandstone can be traced almost uninterruptedly around the Washington area; it extends many miles farther south and west into the interior than does the Pittsburgh sandstone; on the western outcrop it is coarser than that deposit and shows the pebbly layers much farther northward, while it extends many miles farther eastward. The north-south area, in which it is not recognizable distinctly by comparison of drillers' records, is not more than 50 miles wide and 100 miles long. The rock varies in structure, often abruptly, so that within a very short distance the topography may change from rude to gentle outlines; but the variations are like those of other sandstones. The conglomerate bands and occasional areas of conglomerate rock on the western outcrop indicate that the source of the Pittsburgh pebbles had become more available. The presence of conglomerate and very coarse sandstone at Pocatalico on the south-east outcrop certainly indicates a source of pebbles not far away, but the occurrence may indicate also a buried valley.

The higher sandstones of the Washington are very indefinite at the north, where the changes are so frequent that the beds must be taken as lentils of no great extent; but the Marietta sandstones of I. C. White are in the southwestern part of the area, where, in earlier times, only irregular deposits existed. This group was named because quarried near Marietta on the Ohio River in Washington county of Ohio; but it is recognizable for scores of miles in each direction within the Central area, where red shales are the striking feature, where the earlier sandstones have disappeared to be replaced with the red shale containing lentils of sandstone. They indicate extensive exposures of coarse rock at the southwest and west.

Sandstones of the Greene or closing formation of the Pennsylvanian tell even more clearly of the changing conditions. The great Fish Creek and Gilmore sandstones near the top of the formation occupy the middle line of the area from their northern outcrop

to their last exposure in West Virginia. They are coarse, loosely cemented and weather into caverns. The area in which they remain is too narrow to afford information respecting the local conditions of deposit. Their presence along the middle line of the area, where the lower formations have little aside from fine materials, marks the approaching close of deposition in the Appalachian basin.

It is evident that the materials for these sandstones had not a common source. The Bonair, east from Alleghania, received its sand and pebbles from the east, from Appalachia; it becomes less coarse as it approaches Alleghania but beyond that ridge it is again coarse, even pebbly. The sands and pebbles of this western prong must have come from the north as did those of the still newer beds of the New River. The Homewood like the Bonair is very coarse in eastern parts of the basin but the pebbles decrease in size as well as number toward the northwest. But in much of western Pennsylvania, the rock is coarse and more or less pebbly. Here again one must look to the north for the source of coarse material; none could come even from the line of the present Allegheny mountains, for there the rock is without coarse elements except along narrow easterly-westerly lines, marking filled valleys, cut probably in the sandstone itself. The fine sands and argillaceous shales, so commonly marking the horizon in Ohio, point unmistakably to the low Cincinnatia at the west as their place of origin. The sandstones of the higher formations extend successively farther toward the interior of the area of deposit, and for the most part become coarser and less firmly cemented as one ascends in the series. The area of deposit was contracting throughout and elevation along the borders permitted the streams to cut down to the coarse beds of earlier formation.

The abrupt variations in structure and composition, laterally and vertically, seem to find explanation in the phenomena of actual river deposits. River phenomena are distinct in the Bonair west from Alleghania. Along the middle line of the old channel way the rock is coarse, usually with abundant pebbles of considerable size, but on each side the coarseness diminishes so that, at the east, one finds sandstone with pebbly layers and, at the west, merely

cross-bedded sandstone with shale. Where the sandstones extend over broad areas, the conditions are less quickly apparent; but the channel-ways of streams across the often flooded plains are marked by the lines of coarse materials, while the migrations of those streams are recorded in pebbly bands at various levels, now on one, now on the other side of the more or less persistent channel-way. The form of the pebbles and of the sand grains is that due to the action of running water; the remarkable freedom from argillaceous matter characterizing so many sandstones and conglomerates could be brought about only by running water supplemented, perhaps, by the winds.

Other features of the sandstones deserve consideration.

Tree-trunks have been observed in sandstones of all ages since the Devonian. Long ago J. Hall found fragmentary stems in the Devonian of New York; Dawson reported them from rocks of the same age in Canada; Sherwood saw them in northern Pennsylvania and Newberry described forms from the Lower Devonian of Ohio. Such stems are not rare in the Upper Pocono (Logan) of Pennsylvania; they have been reported from the New River beds of Ohio, the Beaver beds of Pennsylvania, Ohio and West Virginia; the Millstone Grit of New Brunswick; the Allegheny beds of Pennsylvania and West Virginia and occasionally from sandstones of higher formations. They are characteristic of Carboniferous sandstones in other areas as well as of those of other times.[46]

In fine grained sandstones one usually finds only small pieces and comminuted fragments of wood but occasionally a large almost uninjured stem has been found, resembling those sometimes dropped on overflow plains by receding floods. Large trunks are not reported from many localities but they have been seen most frequently in coarse sandstones. Hildreth saw some more than 30 feet long in a Beaver sandstone on the Kanawha River; another stem, in

[46] S. P. Hildreth, *Amer. Jour. Sci.*, Vol. XXIX., pp. 22, 37, 73, 76, 107; L. Lesquereux, Geology of Pennsylvania, 1858, Vol. II., p. 840; F. Platt, Sec. Geol. Surv. Penn., Rep. H, 1874, p. 23; A. Sherwood, ibid., Rep. G, 1878, pp. 21, 38–40; I. C. White, ibid., Rep. Q, 1878, p. 203; Rep. Q2, 1879, p. 137; U. S. Geog. Surv. W. of 100th Mer., Vol. III., Supp. 1881, p. 196.

probably an Allegheny sandstone on the same river, was not less than 50 feet long. As a rule, the fragments mentioned by observers are much smaller, rarely exceeding 7 or 8 feet; they are broken at the ends, without trace of root or branch; some appear to have retained their bark when entombed, but, in a great proportion of the instances, the rock contains indeterminate casts of the stem with scattered impressions of the bark. The battered fragments are unquestionably those of floating wood which had long endured exposure, while those which show no injury, aside from loss of roots and branches, were probably prostrate stems carried from a flooded plain. There seems to be no general distribution of stems in any sandstone; in each case the occurrence is noted by the observer as an interesting local phenomenon. If the materials had been carried out to a great basin, where the plant remains could float until water-logged, there would have been a general distribution over a wide area, such as that described by A. Agassiz as existing off the coast of Lower California and in the Caribbean; but the condition is wholly different in the Coal Measures sandstones and bears close resemblance to that observed in the rivers of this day, where logs and undermined trees are stranded on the banks or on gravelly islands to be attacked by successive floods and, after removal of the fragile portions, to be buried in the accumulating deposits.

The less injured fragments, retaining the bark, differ much from those found in coal beds in that commonly they are but slightly deformed by pressure—and this in spite of the fact that ordinarily they are merely casts surrounded by brilliant coal from the bark. Prostrate trunks in coal beds are flattened, while stumps in the coal retain the wood, converted into mineral charcoal and surrounded by the brilliant coal. It may be that the uncompressed stems were those thrown upon sandy bars to decay slowly and to have the interior replaced with sand, while the battered fragments may have remained long above reach of ordinary floods, to be swept away only after loss of the interior. But in any event, one must recognize that the small quantity of the wood found in sandstones is a very important matter; the sandstones and con-

glomerates mark times when activity of denuding agencies was greatly increased, when the destructive effect of floods upon vegetation ought to be most marked.

Surface features of sandstones received little attention from earlier observers in the Appalachian basin. Ripple marks, sun cracks and rain prints seem to have been regarded as mere commonplaces and the recorded observations are merely incidental. Observers in recent years have recognized the importance of these surface markings.

The ripple or wave marks on some Silurian sandstones attracted attention long ago, as they are exposed in broad spaces and, for the same reason, occasional references are to be found to similar markings on some Devonian beds. The earliest note respecting their occurrence in Carboniferous rocks in that by Rogers,[47] who says of the sandstones of Formation X that "beautiful ripple markings are often met with on the surface of the large slabs of the finer of these sandstones." This formation is equivalent to the Upper Pocono of Pennsylvania; and the observation is important because it was made in the area where the earliest coal beds were formed. The rocks are in the lowest division of the Mississippian or Lower Carboniferous.

H. D. Rogers, J. P. Lesley, B. Halberstadt and G. P. Grimsley have recorded observations of wave marks and mud cracks in the Mauch Chunk of Pennsylvania and West Virginia; and J. Barrell has discussed their importance in a memoir to which reference will be made on another page.

Scattered observations show that such surface markings are of common occurrence in Pottsville rocks.[48] Smith obtained a fine slab of sun-cracked sandstone of New River age near Huntsville, Alabama; Ashley reports sun cracks in New River sandstones of

[47] W. B. Rogers, "Report of the Geological Survey of the State of Virginia for 1837," reprint, Boston, 1884, p. 183.

[48] E. A. Smith, letter of December 23, 1911; G. H. Ashley, letter of October 24, 1911; J. W. Foster, cited by J. P. Lesley in "Manual of Coal and its Topography," Philadelphia, 1856, p. 105; I. C. White, Sec. Geol. Surv. Penn., Rep. Q3, 1880, pp. 194, 195.

Cumberland and Rhea counties, Tennessee, the former being on the western, the latter on the eastern outcrop; Foster described a coarse sandstone on Licking River, Ohio, with ripple marks and indistinct fucoids, the latter being most probably casts of sun cracks. White reports the flags at a quarry in Mercer county of Pennsylvania as showing both ripple marks and rain prints.

The writer finds no record of ripple marks or sun cracks on sandstones of the Allegheny. Several correspondents assert that they have seen them frequently but cannot remember the localities as no entries were made in the note books. Condit[49] observed excellent examples in the Conemaugh of Ohio at 15 feet below the Pittsburgh coal bed and at 60 feet below the Ames limestone. Stevenson saw in Fayette county of Pennsylvania a Conemaugh sandstone of which the layers, exposed in a quarry, are covered with irregular ripple marks, closely resembling those made by winds on dunes or sand plains. A laminated sandstone at 57 feet below the Pittsburgh coal, in Allegheny county, is ripple marked on many of the surfaces. In Fayette county, the shales overlying the Pittsburgh coal frequently contain thin layers of ripple marked sandstone and in Greene county the Pittsburgh sandstone shows the irregular trails known as *Spirophyton*. In Fayette and Westmoreland counties, ripple-marked surfaces characterize the Waynesburg sandstone at the base of the Washington formation. The uniform testimony of those who have studied the Appalachian basin is that ripple marks and sun cracks are familiar phenomena in the Coal Measures sandstones or in the clayey films separating the layers.

Footprints in sandstone have been reported from but one locality. King long ago announced the discovery and the occurrence was confirmed sometime later when he and Lyell[50] studied the rock together. The quarry in a Conemaugh sandstone was about 5 miles southeast from Greensburg, Westmoreland county, Pennsylvania.

[49] D. D. Condit, letter of February 14, 1912; J. J. Stevenson, Sec. Geol. Surv. Penn., Rep. K, 1876, pp. 99, 200, 208, 309; Rep. KK, 1877, pp. 31, 208.

[50] C. Lyell, "On Footmarks Discovered in the Coal Measures of Pennsylvania," *Quart. Journ. Geol. Soc.*, Vol. II., 1846, pp. 417–420; Vol. VII., 1851, p. 244.

The sandstone, in thin flags used for paving, is divided by laminæ of unctuous clay, which received and retained the impressions. Twenty-three footprints were obtained, all of them on the under surface of slabs, casts in relief of impressions made upon the clay. There were also casts of shrinkage cracks in the clay, made after the footprints were formed. Rain prints were observed on the slabs which Lyell took to England.

The sandstones in other coal fields have similar markings; Ashley has described ripple-marked sandstones in Indiana and J. A. Udden has found them in Illinois. Dawson,[51] who recognized the importance of recording all observations, has noted the occurrence of ripple and rain marks as well as of footprints at many localities within the Acadian areas. A sandstone in South Joggins shows distinct rain and footprints; on the shore of Northumberland strait, where the strike coincides with direction of the shore, great surfaces are exposed with ripple marks and worm trails. In 1842, he found, near Tatamagouche, footprints on a rippled surface and in 1843 he discovered two other series of prints, one of which was somewhat defaced by rain marks. Many beds within this region have ripples, rain marks, worm trails and sun cracks in clay laminæ within the sandstones. Lyell summarized the information respecting them. Hull has recorded similar conditions in Lancashire of England and Miller has described the footprints at Dalkeith in Scotland.[52] Similar markings are reported from almost all the large coal areas, and they are characteristic of sandstones containing laminæ of clay on which the markings were impressed.

Many authors have noted the "Vegetable soils" or "Ancient soils" observed in sandstone. These may be marked by local deposits of coal or by erect trees *in situ,* with or without traces of coal around the roots.

[51] J. W. Dawson, "Acadian Geology," 2d ed., 1868, pp. 167, 215, 217, 325, 328, 355, 357, 410; Supplement, 1878, pp. 62, 64.

[52] C. Lyell, "On Fossil Rainmarks of the Recent, Triassic and Carboniferous Periods," *Quart. Journ. Geol. Soc.,* Vol. VII., p. 244; E. Hull, "Geology of the Country around Wigan," 2d ed., Mem. Geol. Surv. Great Britain, 1862, pp. 9, 10.

The official reports note the not infrequent occurrence of coal patches in sandstone, some of them only a yard but others several rods long and wide. Without doubt, not a few of these are merely blocks of vegetable matter removed by sand-laden streams during change of channel-way; but others, such as that described by I. C. White,[53] are unquestionably *in situ*. In this case, the deposit is of impure cannel, 5 feet thick where opened, but disappearing in all directions within a few rods. It evidently marks the site of a shallow pond on the sandy surface, which was filled with sapropel material. It is probable that a similar explanation applies in many other cases, as impure cannel is the usual material.

Not many references to erect trees in sandstone are to be found in reports on the Appalachian basin; such trees, for the most part, are rooted in shales. Lesquereux[54] has mentioned the occurrence of a forest of *Sigillaria* and *Calamites* in sandstone over the great coal bed at Carbondale in the Northern Anthracite field. This seems to be the only recorded instance where the relations are clear; but Dawson[55] observed several ancient soils in sandstone. His Division II., 650 feet thick, has two old soils with erect trees; Division III., 2,134 feet thick, has many with erect trees, the old soils being in most cases very thin shale enclosed in sandstone. At one locality this thin shale bears erect *Calamites* and shows rain prints as well as footprints of batrachians; another, somewhat lower, with erect stems, has yielded several species of batrachians as well as remains of insects and land mollusks; at another, the sandstone cliff shows trees as pillars of sandstone and with them are associated *Calamites,* all vertical to the bed, which is inclined at 19 degrees. Here the sandy flat, supporting the trees, was inundated and covered with sand; in time, the trunks rotted and were broken off to be covered by the increasing deposit, which filled the interior of the decaying stem. At another horizon, one stem rises 4 feet and is surrounded by sandstone and the succeeding shale, but another reaches only to the top of the sandstone. On this sandstone there

[53] I. C. White, Sec. Geol. Surv. Penn., Rep. Q, 1878, p. 202.

[54] L. Lesquereux, "Geology of Pennsylvania," 1858, Vol. II., p. 840.

[55] J. W. Dawson, "Acadian Geology," pp. 156–178.

grew a forest of *Calamites,* which, in their turn, were surrounded by the mud, which reaches to the top of the larger *Sigillaria.* This growth of *Calamites* on sand, which had buried the *Sigillaria,* recalls the conditions at Topeka, Kansas, already described, where during a great flood the young trees of a large nursery were buried by sand, on which a dense growth of cottonwoods developed within a few weeks. The conditions recall also those described by Russell on the Yahtse River in Alaska. The trees were killed, not broken by the mass of gravels; the trunks decayed, some were broken off by the wind and the stumps were buried under new material brought down by the river, but others remained, at the time of Russell's examination, projecting many feet above the surface.

The evidence all points in one direction. The buried channel-ways, the cross-bedding reported at many localities and the rounded pebbles indicate river not shore deposit. Plants buried *in situ* by inundation, the ripple-marked and sun-cracked surfaces, the rain prints, the footprints of batrachians, the pool-like accumulations of vegetable matter, the absence of marine fossils and the distribution of the coarser materials make up, altogether, a mass of evidence which it is difficult if not impossible to controvert. The sandstones were great flats, subject to inundation by the rivers to which they owed their origin. There appears to be no evidence to support the supposition that they are either shore or deepwater deposits.

The Shales.—Coal Measures shales vary in structure from merely compacted muds to finely or coarsely laminated beds; in composition from fine clay to sand or impure limestone; in color from almost white to black, the latter often passing to cannel or even to ordinary coal. Thick deposits of shale frequently hold lenses of sandstone and similar lenses of shale occur in sandstone. Some shales are rich in remains of a marine, a brackish water or of a freshwater fauna; others are crowded with impressions of land plants, retaining the most delicate markings of all parts; others have only indistinct plant remains, with which a marine fauna sometimes occurs; others still, of notable thickness and area, have rare and mostly obscure traces of either vegetable or animal life.

Sandstone predominates in the Pottsville but in later formations shale is a characteristic feature. This is true of the anthracite area almost equally with the bituminous region, as appears from the sections and drill-hole records published by the Pennsylvania survey.[56]

The anthracite region, including the broad eroded spaces between the coal fields, is about 70 by 100 miles, but the coal area, which has escaped erosion, is considerably less than 500 square miles. The Pottsville deposits are almost wholly sandstones or conglomerates except locally in the Eastern Middle, where the Beaver shows here and there thick beds of shale, 22 to 42 feet thick. Conditions changed gradually after the beginning of the Athens, so that above the Mammoth coal bed, identifiable with comparative certainty throughout much of the area, one finds abundance of shale. At the northeast in the Southern field, one section has 194 feet of shale in a total of 218; another has one bed, 64 feet, and three thinner beds in 257 feet; midway in the field, some sections show nearly one half shale in 900 feet above the Mammoth. There is much variation in thickness and in position of the shale beds and none is persistent in all the sections. In the Western Middle, the thickest bed at the easterly end is but 40 feet, but farther west are beds of 45 to 107 feet with others of less thickness, while at the western end shale and sandstone are often in equal thickness. The proportion of fine shale above the Mammoth is as large as in most of the bituminous region and some of the beds are thicker than any there outside of the central space in West Virginia. Farther south along the eastern border in Alabama, where only the Pottsville remains and the conglomerates are thick and coarse, one finds great beds of finer materials, though argillaceous shale seems to be comparatively unimportant.

Sandy shales are closely related in distribution to the sandstones; black or carbonaceous shales will be considerd in connection

[56] The survey of the anthracite fields was planned by C. A. Ashburner and was executed under his direction. His death occurred after completion of the work but before preparation of the report. Discussion of the results was assigned to A. D. W. Smith and it is given in Vol. III. of the Final Report.

with coal beds; it is necessary here to study in detail only the red shales and to note a few matters concerning shale deposits generally.

The Red Shales.—The red and green muds and laminated sandstones of the Catskill pass gradually into the early Carboniferous in a great area within Pennsylvania and Virginia. In like manner, the red shales of the Upper Mississippian pass into the Pottsville through a transition series of sandstones, conglomerates and red to green shale beds, this feature being especially characteristic in the southern anthracite field, where the column is complete. The reds and greens of the Catskill mark a condition, which originated in southeastern New York during the Middle Devonian and spread slowly west and southwest, reaching southwestern Pennsylvania late in the Chemung, the last great division of the Devonian. The condition, whatever its cause may have been, appears to have been without relation to the character of the water; the fauna in the northern portion of the area is freshwater, but in southwestern Virginia,[57] very near the termination of the red deposits, *Spirifer disjunctus* and some other forms were obtained at the top of the formation, showing that marine conditions reached as far northward as New River and that they were not inconsistent with the deposition of red beds. The Mauch Chunk or Upper Mississippian red beds seem to have yielded no marine forms in eastern Pennsylvania, but in southern Pennsylvania and southward, the middle and lower portions are gradually replaced with the Maxville limestone, which is marine, while in western Pennsylvania the upper portion or Shenango shale has yielded marine forms in Crawford, Mercer and Fayette counties.[58] The fossils are large and they did not live amid unfavorable conditions. The shales are red in Fayette county, so that again it is evident that influx of salt water did not prevent formation of red beds. The Pennsylvanian red shales have neither the constancy nor the extent of those in the Catskill and Mauch Chunk, but they resemble the former in that the conditions favoring their formation existed at first in a small area, whence they gradually spread; they differ

[57] J. J. Stevenson, "The Chemung and Catskill on the Eastern Side of the Appalachian Basin," *Proc. A. A. A. S.*, Vol. XL., 1891, separate, p. 7.

[58] I. C. White, Sec. Geol. Surv. Penn., Rep. Q4, 1881, p. 77; J. J. Stevenson, ibid., Rep. KKK, 1878, p. 308.

in that after a maximum area was reached, the conditions ceased to be general, became more or less localized and the deposits were isolated, at times widely separated.

The earliest appearance of the Pennsylvanian reds is in the New River of northwestern Georgia, where two beds, 11 and 35 feet, were found, with 103 feet of variegated shale intervening.[59] No reds are reported from the Pottsville of the anthracite region and they are rare in the Allegheny, occurring only in the lower part of that formation. A bed, 32 feet thick, was found near Drifton in the Eastern Middle at 30 feet below the Buck Mountain coal bed and, near Harleigh, a thin bed underlies that coal. In the northern part of the field, a soft red sandstone is at a few feet below the Mammoth and near Harleigh a thin bed of red sandstone overlies the Buck Mountain; at a few miles west, in the Western Middle, some thin streaks of red shale exist between the Buck Mountain and the Mammoth. These are all within a narrow north and south space and must have been brought down from the Alleghania slope.

Red shale first appears in the bituminous region during the latter part of the Allegheny. The most southerly locality is in Boyd county of Kentucky, where 18 feet of green and red shale were seen near the top of the formation. The deposit is altogether local, for measured sections and well records in adjoining counties of Ohio and West Virginia show no trace of red at this horizon. The nearest notable deposit is more than 80 miles distant toward the northeast in Washington county of Ohio, where 64 feet of red shale begins at 503 feet below the assumed place of the Pittsburgh coal bed and so extends downward to the middle of the Allegheny. There, one has reached what may be termed the Central area, in which red shales are a striking feature from the middle of the Allegheny to the close of the Pennsylvanian. This area embraces contiguous portions of Washington county of Ohio, Wood, Ritchie, Wirt, Calhoun, Roane, Jackson, Gilmer and Clay counties of West Virginia, in all not far from 3,500 square miles. Red shale in the Allegheny is reported here and there from other counties but in each case the deposit is insignificant.

[59] J. W. Spencer, "The Palæozoic Group," Geol. Surv. Georgia, 1893, p. 139.

At the beginning of the Conemaugh, one finds on the eastern and northern parts of the bituminous region an important sandstone, which becomes unimportant on the western outcrop in Ohio. In several counties within the Central area, its place is occupied by red shale. The same material occurs in occasional borings farther north near the Pennsylvania line and thin streaks are reported in a few wells north from that line; but these occurrences seem to be isolated. As one rises in the Conemaugh, he finds the areas increasing, for widely extended deposits appear below the Cambridge, the first persistent limestone of the Conemaugh. At this horizon the reds, though variable, are thick in some portions of the Central area and very irregular in others; but conditions favoring deposition of reds existed at many localities, somewhat widely separated; such deposits are reported from the Central area; from Ohio at 100 miles toward the west; from the northern counties of West Virginia; from several counties in southwestern Pennsylvania as well as from Webster county of West Virginia on the eastern outcrop. Away from the Central area, most of the deposits are thin, apparently of small area; their interrelations cannot be ascertained but there is no doubt that many of them were wholly isolated. They suffice to show that, prior to the formation of the marine Cambridge limestone, conditions favorable to deposition of red shales existed at very many localities within an area of not less than 10,000 square miles.

The Pittsburgh reds of I. C. White underlie the Ames limestone, which carries a marine fauna and is midway in the Conemaugh. This interval between the two marine limestones is marked by the greatest expansion of reds within the Appalachian basin. No trace of the deposit is seen on the eastern side of the bituminous region except in a small space within western Maryland and the adjacent part of Pennsylvania. Aside from that locality it seems to be absent along the eastern outcrop in Pennsylvania and West Virginia as well as along the western outcrop in Ohio. But in the interior portion of the bituminous region the Pittsburgh reds are present from Boyd county of Kentucky to the northern outcrop, a distance of 275 miles, and the width at times is 80 miles, giving an area of certainly not less than 17,000 square miles. The thickness varies; it becomes almost 250 feet in some localities, when the mass is continuous below

with that under the Cambridge limestone and at others where it is continuous with that above the Ames; but it is notable throughout its whole extent; even at the northern border, where no other reds are found in the Conemaugh, the Pittsburgh reds are from 30 to 50 feet thick. At the same time, it must be noted that this, like those which precede and those which follow, is in no sense a uniform deposit; the variations in thickness and character are greater than those of the sandstones and are marked by extreme irregularity. Making all allowance for defective methods of keeping the records of borings, one must recognize that a mass of red shale, 50 feet thick in one well, may be replaced, even in the Central area, with sandstone in another well only 200 feet away; that red shales alternate vertically with light gray, blue or almost white shales as well as with gray white or bluish sandstones; comparison of well records, preserved and collated by I. C. White in the West Virginia reports, leaves no room for doubt that red shales are often continuous laterally with light colored shales and sandstones, and that the transition may take place within a few rods. But in the upper portion, the Pittsburgh reds are as nearly continuous throughout the whole area as is any other deposit in the series.

The Washington reds, the "Big reds" of the drillers, follow the Ames limestone and, where that rock is absent, are often continuous with the lower deposit. This mass spreads with considerable thickness into counties adjoining the Central area but it underlies not much more than 4,000 square miles and is absent at many places even within the main red area. It seems to be wanting in most of Ohio, but a thickness of 60 feet is reported in Muskingum county at 50 miles from a locality on the Ohio River, where it is said to be 100 feet thick, no reds having been observed in the intervening space. It occurs as red shale occasionally in northern West Virginia but seems to be wanting in Pennsylvania, though its place is marked by the fine-grained Birmingham shale of that state. Its variations laterally and vertically are wholly like those of the Pittsburgh. The area of red shows more notable contraction in the upper part of the Conemaugh, but, locally, the reds were deposited in an area almost as great as that of the Pittsburgh. Thick deposits are reported from some counties within the Central area and none whatever from

others; isolated deposits are reported from 9 counties of Pennsylvania and from 6 in Ohio but there seems to be very little in the greater part of West Virginia. The total area of the reds during the later Conemaugh at any one time was less than 1,000 square miles and the deposits are widely separated. At the same time, one must note carefully that, while the deposits are usually of small superficial extent, yet the thickness of some is important.

The conditions during the Monongahela were much like those at the end of the Conemaugh but the area in which deposits were made is much less. No red is reported from Pennsylvania except a thin streak at one locality, nor is there any in the West Virginia panhandle. There is none in Ohio except near the Ohio River toward the Central area. But, as one approaches that area, the red increases and some of the beds are important. In West Virginia, there seems to be very little along the eastern side north from the Kanawha River and in the interior the occurrences are few and irregular until one comes to the Central area, where beds are many but more irregular than at any time during the Conemaugh. In Ritchie county, every foot of the section for 300 feet above the Pittsburgh coal bed is marked by red shale in some well or another; but that statement tells little respecting the conditions. The beds vary from 7 to 110 feet as measured in different records; in some borings, one finds 220 feet of red in a vertical distance of 300 feet, while in others near by the total is less than 100 feet. Similar variations are found in other counties but the maximum thickness is less. Aside from the insignificant and distant patches in Pennsylvania and Ohio, the area in which reds were deposited at various times during the Monongahela is less than 4,000 square miles and no deposit has great superficial extent.

During the Washington, local conditions favoring deposition of reds existed here and there in a much greater area; but the conditions were local. Reds are reported from three localities in Washington and two in Greene county of Pennsylvania; from six in Ohio; from a number of places in northern West Virginia; but these are all far apart and the most of them are insignificant. Only when one reaches the Central area does he find the deposits assuming importance. Even there the occurrence is indefinite; a boring in Wood

county, West Virginia, passed through two beds, 100 and 60 feet thick, but in another well, only a short distance away, the same intervals show 60 and 20 feet of red. Greater contrasts appear elsewhere, for thick deposits of red in one well are replaced with sandstone in another, less than one eighth of a mile distant.

The story is the same for the Greene. In southwestern Pennsylvania deposits, 50 to 90 feet thick, were seen, but they are local, being absent in sections four or five miles away. There are certainly some reds in the formation within the West Virginia panhandle, but the exposures do not admit of measurement. Some important deposits are reported farther south along the Ohio River but for the most part little information exists respecting them. The Greene formation in West Virginia contains nothing of economic worth and, with the exception of one persistent limestone, there are no definite horizons. There seems to be only a monotonous succession of shales and soft sandstones, all ill-exposed. But, in riding across the Central area, one recognizes at once that red shale forms no insignificant portion of the mass, though the imperfect exposures suggest that the deposits must be lenticular like those in the earlier formations.

Red shales are found in other coal basins and in later formations. Dawson[60] found them abundant in all divisions of the Coal Measures from the Millstone grit to the top and with the same features as in the Pennsylvanian of the Appalachian basin; gray and red shales alternate vertically and at times are continuous laterally. Conditions are the same in later times; lenticular deposits of red clays occur in the glacial till of Canada and of Scotland. The great Pampean formation as originally described by Darwin[61] would seem to be a continuous deposit of reds covering an area almost equal to that of France; but it varies in composition as reds do elsewhere, for records of borings near Buenos Ayres show that the section consists of sand, clay and green shale. Church, to whose studies reference will be made on a later page, found that a vast area of the Plata region is covered with reddish-yellow, semiplastic argillaceous earth, contain-

[60] J. W. Dawson, "Acadian Geology," pp. 156–176.

[61] C. Darwin, "Journal of Researches," New York, 1846, Vol. I., pp. 161, 164, 165; "Thickness of the Pampean Formation near Buenos Ayres," *Quart. Journ. Geol. Soc.*, Vol. XIX., 1863, pp. 68–70.

ing at times, calcareous nodules. The deposit is without pebbles and becomes increasingly sandy toward the west. The Pampean formation resembles the Pittsburgh reds. Gruner[62] has observed that in the Loire basin, red beds are not uncommon in the sterile stage of Saint-Chamond. The deposits are found at all horizons in this formation which is from 650 to 2,600 feet thick and is the middle division of the Loire Coal Measures. In the Lancashire field of England the reds appear to be confined to the upper Coal Measures.

Dawson found abundance of ripple marks, rain and footprints in the Acadian red shales but no record of such markings on the Pennsylvanian reds has come to the writer's notice. Fossil remains, vegetable or animal, are rare, but Raymond[63] discovered reptilian bones in a small basin eroded in the sandstone on which the Pittsburgh red shales rest. Not infrequently the red muds contain nodules of ferruginous limestone in which are marine fossils; these abound in the Pittsburgh reds and cause much annoyance to drillers of oil wells. At one locality in West Virginia on the east side, the Pittsburgh reds are replaced with a succession of variegated shales which are exceedingly rich in marine forms, several of which pass upward into the Ames limestone; and the shales are similar at 25 miles southwest. The Pittsburgh reds, at least in part, were deposited where salt water had access. There is much to suggest similar origin for some other reds. Those below the Cambridge pass upward to that limestone as the Pittsburgh reds pass to the Ames. In considerable areas they replace the limestones and the two deposits are continuous with each other or even with the Washington reds above. The limestones are wedges in the shale as the Maxville becomes a wedge in the Mauch Chunk shales within southern Pennsylvania. The Washington reds are equivalent in position to the Birmingham shales at Pittsburgh, which Raymond, in the publication cited above, has shown to be marine. It is certain that marine conditions are in no wise antagonistic to deposition of red shale. At the same time, one must not forget that the conditions must have been very different

[62] L. Gruner, "Bassin houiller de la Loire," Paris, 1882, p. 217.

[63] P. E. Raymond, "A Preliminary List of the Fauna of the Allegheny and Conemaugh Series in Western Pennsylvania," Topog. and Geol. Surv. (of Penn), 1911, p. 89.

for isolated deposits, which are numerous and often thick. These, in many cases, were far away from any marine invasion, in regions of coal beds and freshwater limestones. Within the Central area, there is almost total absence of limestone, the coal beds are indefinite and most of those which are recognized on the borders are wholly wanting.

The origin of the red color in shales and sandstones has been sought by many students. Crosby[64] has shown that in the northern United States and Canada the soils are rarely red except when derived from a red rock; but southward from latitude 39° redness increases until, in the West Indies and South America, it becomes intense. The color is not due to the rocks, for the red deposit at the south rests on primary rocks not differing from those at the north where no red is found. He thought that the contrast is due, very probably, to climate, the dehydration of ferric hydrate and consequent change of color being caused by solar heat. In a later paper, he says that six years of additional study had led him to assign less importance to solar heat as the converting agent, but he still recognizes it as one of the important agents. Many illustrations are given, which certainly appear to go far toward fortifying his position.

Russell[65] took up the subject at a somewhat later date and reached conclusions differing from those of Crosby. The depth to which decay of rocks extends in the Appalachian region increases southwardly, becoming 100 feet in large areas, and he cites Belt as reporting that, in Nicaragua, the depth at times is 200 feet. In the great limestone valley, south from James River in Virginia, the clay remaining after solution of the limestone is red and sometimes 50 feet thick. He objects to the conclusion that climate or solar heat caused the red color, because in summer the soil is heated as strongly in the northern as in the southern states. The red beds of the Rocky

[64] W. O. Crosby, "Colors of Soils," *Proc. Bost. Soc. Nat. Hist.*, Vol. XXIII., 1885, pp. 219–222; "On the Contrast in Color of Soils of High and Low Latitudes," *Amer. Geol.*, Vol. VIII., 1891, pp. 78–82.

[65] I. C. Russell, "Sub-aerial Decay of Rocks," U. S. Geol. Surv. Bull. No. 52, 1889.

Mountains could not have become red by exposure during deposition, for the playa beds in Nevada and similar regions are creamy white, though the summer temperature reaches 110° to 120° in the shade. The red color was acquired during decomposition of the rock and consequent incrustation of the grains. Richtofen has explained the red of the Rothliegende by supposing that during the Carboniferous there was deep decay of the rock and that this material became that of the Rothliegende. Russell applies the same explanation to the great red deposits of America, which he regards as formed of debris from rocks long exposed to a warm moist atmosphere.

Beede's[66] studies are in place here. It had been ascertained that the light-colored sediments of Lower Permian in Kansas become red in Oklahoma and the same condition was observed in going northward into that state from Texas; in one instance a limestone was traced into a sandstone. Beede, following the Kansas deposits into Oklahoma, found that limestones became sandy in patches, which increased until the limestone disappeared. Farther south the sandstone becomes deep red or brown with patches of white. The limestone fauna reaches southward only a little way beyond the limit of that rock. Shales become red much farther north than do the sandstones and often have deeper color; even the limestone, at times, becomes reddened before disappearance. The sandstones vary much in thickness at expense of the shales, but the thickening is irregular, the rock is cross-bedded and often shows ripple marks. At their southern limit, the shales and sandstones dovetail into Permian conglomerate on the Arbuckle and Wichita mountains, which is formed largely of the limestone, at one time covering those mountains and even now 8,000 to 10,000 feet thick on their flanks. These limestones yield a residual red clay, while the disintegrating conglomerate yields a red sandy clay resembling that of the red beds. It would appear that the lower red beds of Oklahoma were derived from the Arbuckle-Wichita land mass and that the coloring matter is due chiefly to solution of limestones known to have been removed from the area. Beede concludes that the deposits, which are void of fossils

[66] J. W. Beede, "Origin of the Sediments and Coloring Matter of the Red Beds of Oklahoma," *Science*, N. S., Vol. XXXV., 1912, pp. 348–350.

and even of carbonaceous matter, were made in very shallow turbulent water or on vast tidal beaches.

Dannenberg,[67] discussing the importance of red beds, refers to activities of changing climatic conditions as perhaps a notable agent in bringing about the contrast between the productive and the barren measures. In the productive measures, one finds constantly dark gray to black as predominating colors, due to impregnation of the whole mass with coaly substance, while the succeeding barren measures are recognizable by the red color. The Rothliegende, succeeding the Carboniferous, owes the first half of its name to this condition. But the change in color begins before the close of the Carboniferous, for the red appears as soon as conditions for coal-making end—with the entrance of red, the formation of coal beds ceases. In the Saarbruck region, reds occur in the Upper Carboniferous over the productive division. That a luxurious vegetation existed during deposition of this unproductive red shale is proved by the presence of great masses of vegetation in the Rothliegende, such as the petrified forest at Radowenz in Bohemia. Evidently not failure of vegetation but changing climatic conditions, which were unfavorable to the accumulation of plant remains, brought about the new features. The formation of red rocks and weathered products is at present a peculiarity of the torrid zone, where one finds laterite, terra rossa, etc., in which humus is unimportant. Dannenberg is inclined to think that in the Carboniferous, there were moderate, perhaps ocean climates contrasting with the succeeding hot climate of the continental Rothliegende.

Barrell,[68] who regards the Mauch Chunk (Upper Mississippian) red shales as, for by far the most part, of flood-plain origin, has published two important memoirs bearing upon the origin of the red color. In the earlier memoir he shows that the Mauch Chunk contains some impressions of plants but no trace of the carbon remains. The loss of carbon has not decolorized the shale, so that evidently

[67] A. Dannenberg, "Geologie der Steinkohlenlager," Berlin, 1910, pp. 30, 31.

[68] J. Barrell, "Origin and Significance of the Mauch Chunk Shale," *Bull. Geol. Soc. Amer.*, Vol. 18, 1907, pp. 449–476; "Relations between Climate and Terrestrial Deposits," *Journ. of Geol.*, Vol. XVI., 1908, pp. 159–190, 255–295, 363–384.

the oxidation was by free oxygen and not by that derived from ferric oxide. The discussion in the later paper covers the whole question and the author fortifies his position with the wealth of illustration that seems to leave little room for disputing his conclusions; but the discussion is so elaborate that only the final statement can be given here and the reader must be referred to the memoir itself for the detailed argument. The red color of ferruginous rocks as contrasted with the predominating yellows of alluvium is due to three coöperating causes: Spontaneous dehydration, operating to some extent at the surface in warmer regions; dehydration under great pressure and moderate temperature, nearly universal in sediments which become buried and consolidated; diffusion, operating under conditions of warmth and moisture, whether these be at the surface as in warm and humid regions or beneath the surface as may occur in any portion of the earth. By these three means, the light-colored yellow or brown muds and sands may become red shales and sandstones. The chief condition for formation of red shales and sandstones is merely the alternations of seasons of warmth and dryness with seasons of floods.

Gruner and Dannenberg lay stress upon the fact that reds occur in the sterile measures. Certainly the reds seem to have been deposited under conditions which were unfavorable to the accumulation of coal, for that is almost wanting in the central area of West Virginia; great coal beds, traceable for hundreds or even thousands of square miles, thin out to disappearance as they approach that area. At the same time one must not forget that the reds mark local, not general conditions; that they abound in the productive as well as in the less productive portions of the column. Within the Central area they are as important in the upper Allegheny and in the Monongahela as in the Conemaugh and Washington. Even in the limited Loire basin the same is true, for the reds there are practically confined to that portion of the Saint-Chamond area, which is micaceous. Whether or not a similar relation exists in the Saarbruck area, the writer has not been able to ascertain.

The distribution of Pennsylvanian red shales forbids the sup-

position that they owe their red color to any widely-acting cause. The especial localization of the deposits in the central part of the area, the lateral passage into fine shales and sandstones of wholly different color and the many isolated occurrences of small deposits seem to exclude explanations based on supposed aridity or any other general condition of climate. The shale, at times, contains small areas of coal in distinct beds, and occasionally one finds coal at the horizon of beds which are persistent around the borders. Where the mass is interrupted by other deposits, which continue to within the limits of the reds, a coal bed also at times continues from the border, though at the east only a few miles away it is wanting as the red is continuous vertically. It is certain that occasionally the conditions, favoring accumulation of coal, existed for considerable periods within the Central area of reds. No matter which hypothesis respecting the formation of coal beds be accepted, the condition of general aridity becomes inadmissible, because the existence of coal beds, great or small, is proof of humid atmosphere and dense vegetation not far away. One finds a great mass of reds at the Pittsburgh coal horizon at less than a score of miles from localities where that bed is of workable thickness; and the same statement is true respecting the Harlem and Anderson coal beds. There is every reason to suppose that in a general way the climate, in respect of rainfall, was very much as now; the direction of the winds was the same and there is no reason to suppose that, at any time during the Pennsylvanian, a mountain chain existed on the west side of the Appalachian basin. Yet alternation of wet and dry conditions, as suggested by Barrell, may have been prevalent, though due only indirectly to atmospheric influence.

Topographic changes would seem to be the preferable explanation for conditions in the Central area. The subsidence, converting that area into vast tidal flats, continued until, just prior to the Ames limestone, the region subject to river and tidal overflow may have embraced more than 20,000 square miles. It must be remembered that in the vertical space occupied by the great reds of the Conemaugh one finds the Cambridge and Ames limestones, both marine. The rivers during long periods of little change had ac-

quired low gradients and they carried little coarse material, which was dropped on the border of the low area, while the streams, flowing sluggishly across the flats distributed the abundant fine materials and, as they shifted their courses, sorted the stuff, giving the lenses of clay and sand. The source of the red material is to be sought at the west, for the reds are present mostly on the west side of the bituminous region—even the great Pittsburgh reds extend only a little way east from the middle line of that region. During contraction of the area of deposition, the Mississippian beds became exposed to erosion while the calcareous deposits of the low-lying Cincinnatia had been converted by solution in their exposed portions into red clays such as one sees in so much of the Great Valley within Virginia and Pennsylvania. During deposition of the Pittsburgh reds, residual soils of the northern land must have been an additional source of supply. It seems wholly preferable to regard the Pennsylvania reds as derived from reworking of deposits already red. At the same time, one cannot suppose that the local and widely separated patches in the Monongahela, Washington and Greene were derived from a distant source. Probably they mark the sites of ponds into which the sluggish streams carried muds due to decay of limestones and mingled with those from the fine shale of the red region.

Surface Markings on Shales.—There are no recorded observations of surface markings on Pennsylvanian red shales within the Appalachian basin, though such markings are sufficiently abundant in the Acadian region. But sun cracks and ripple marks are common enough on shale beds of other types. Footprints were found by Mason[69] on slabs of slate from the roof of the Mammoth coal bed. The surfaces show occasional ripple marks along with the tracks of a four-footed animal arranged in regular sequence. This appears to be the only case recorded within the Appalachian. There is little reason to expect such discovery in the bituminous

[69] W. D. H. Mason, "On the Batrachian Foot-tracks from the Ellangowan Shaft in Schuylkill Co., Penn.," *Proc. Amer. Phil. Soc.*, Vol. 17, 1878, pp. 716–719.

region, where one has only natural exposures for study and the shales are so easily disintegrated that only the basset is exposed. Woodworth[70] studying the more or less indurated shales of the Massachusetts region was led by discovery of rain prints to look for batrachian footprints. The search was rewarded almost at once by discovery of impressions belonging to two individuals. Study of the prints convinced him that they were made under slight cover of water. Many scratches were found on the shale surface, resembling those made by the sharp toes of newts in very shallow water.

In situ forests occur frequently in shale beds. Gresley[71] reported that 7 erect trees were found in the roof of the Buck Mountain coal bed at Haven River colliery. He says that tree-stumps with *Stigmaria* roots are of common occurrence in the roofs of several anthracite beds. That of the Baltimore at Wilkesbarre yielded one, 36 inches in diameter at a few feet above the roots. Comparatively few instances of trees *in situ* have been recorded in the coal fields of the United States and most of the notes, which the writer has found, seem to have been made incidentally and are without detail, as are most of those with reference to similar occurrences in sandstones.[72] Long ago Owen[73] described a forest discovered at 12 miles from New Harmony, Indiana. More than 20 fossil stumps had been found in excavating the site for a mill and dam. He disinterred three with 5 to 7 main roots, which ramified in the surrounding material. As these trees, trunks and roots were in normal position, he believed that they had grown there and had

[70] J. B. Woodworth, "Vertebrate Footprints on Carboniferous Shales of Plainville, Massachusetts," *Bull. Geol. Soc. Amer.*, Vol. 11, 1900, pp. 449–454.

[71] W. S. Gresley, "Seven fossil Tree Trunks, probably *in situ*, found in Roof of a 12-feet seam of Anthracite in Schuylkill Co., Penn.," *Trans. Manch. Geol. Soc.*, Vol. XXI., 1890, p. 70.

[72] There is ample reason to expect that when D. White publishes the results of his investigations, all grounds for this complaint will disappear.

[73] D. D. Owen, "On Fossil Palm Trees," *Amer. Journ. Sci.*, Vol. XLV., 1843, pp. 336, 337.

become submerged quietly. Lyell[74] visited this locality at a later date when a quarry had been opened in the overlying sandstone. He saw the trees in a clay shale underlying sandstone and 18 feet above a coal bed. He, with Owen, dug the clay from about one of the trees, which was 4 feet 8 inches high and with roots spreading out as in the normal position. This and two other *Sigillaria,* close by, were casts, the bark converted into coal but the interior filled with mud. The roots were interlaced. A great number of such trees had been removed in working the quarry. Udden[75] notes that a vertical stump resting on a coal bed was seen by him near Peoria, Illinois, but he gives no details aside from the statement that the stump is filled with sandy clay.

There is, however, no lack of information respecting other lands. Dawson and R. Brown have recorded many instances in the Acadian region; in one case there are *Sigillaria* stumps with *Stigmaria* rootlets descending among them from an overlying bed. Occasionally an embryo coal bed existed in the old soil but in some cases there is no trace of coal. The absence of vegetable matter around the base of the stems is in no sense evidence that they are not in place, for Tuomey, as cited on an earlier page, has shown that peat beds raised above the level of water-supply, waste away by drying, the removal being aided by the winds, which carry off the dust-like material. The trees remain, rooted in the underlying soil. Many other students of peat deposits have made the same observation in later years. Gruner says that the lower forest of Treuil has the roots spread out in the roof of the coal and that it is present except where the roof has been washed away and replaced with sandstone. Hawkshaw[76] described the trees found at Dixon Fold near Manchester. Five of them, at nearly right angles to the stratification, were embedded in a soft blue clay, and a thin coal bed on same

[74] C. Lyell, "A Second Visit to the United States of North America," 2d ed., 1850, Vol. II., pp. 272, 273.

[75] J. A. Udden, "Geology and Mineral Resources of the Peoria Quadrangle," U. S. Geol. Surv., Bull. No. 506, 1912, p. 37.

[76] J. Hawkshaw, "Descriptions of the Fossil Trees found in the Excavations for the Manchester and Bolton Railway," *Trans. Geol. Soc.,* II., Vol. VI., 1842, pp. 173–175.

plane as the roots continues as far as the excavation extends. *Lepidostrobus variabilis* occurs abundantly about the level of the roots, more than a bushel of specimens having been obtained around the trees. A coating of coal, one fourth to three fourths of an inch thick, surrounded the trees, so tender that it flaked off and left the stems decorticated; but some harder coal near the roots of one tree showed the bark fluted longitudinally. The largest tree was 11 feet high, 15 feet in circumference at the base and 7 feet and a half at the top. The next in size was 6 feet high, seven and a half feet in circumference and less tapering; the others were shorter. The roots could be followed only a short distance owing to the character of the excavation. They are covered with a thin stratum of coal, 8 to 10 inches thick, which Hawkshaw thinks probably represents the vegetable covering of the place on which the trees stood.

Binney[77] says that when erect trees were first found, an attempt was made to refer them to accidents as snags; but discoveries by Hawkshaw and Bowman, near Manchester, aided toward recognition of their growth *in situ*. During a recent examination of excavations for the Bury and Liverpool railway near Wigan, he had discovered not merely a forest of erect *Sigillaria,* with roots just as they had grown, but also many *Calamites* in similar state of preservation. The excavation is about 25 feet deep and in a light gray, silty clay very like that at St. Helens and Dukenfield, where the earlier discoveries were made, and the deposit is between two coal beds. In a distance of 50 yards, he found 30 upright trees and some prostrate stems of *Sigillaria*. They were 2 to 3 feet in diameter, 2 to 12 feet high and filled with silty clay, the bark having been converted into brilliant coal, one fourth of an inch thick. Many *Calamites* were seen among the trees, 4 to 5 feet high, one to 5 inches in diameter, with a thin coaly crust and filled with the silty clay. Each type occurred in all parts of the deposit from top of the lower seam to bottom of the upper. During a second

[77] E. W. Binney. "On Fossil Calamites found standing in an erect Position in the Carboniferous Strata near Wigan, Lancashire," *Lond., Edinb. and Dubl. Phil. Mag.*, Vol. XXXI., 1847, pp. 259–266.

visit with Hooker, he discovered *Calamites* with rootlets from joints along the stem. These he describes in detail.

Sorby[78] relates that 8 large well preserved stumps had been found at Wadsley, rooted in a clay-like shale; all of them *Sigillaria* with *Stigmaria* roots. The tops are flat as though sawed off. The largest stump is 5 feet 2 inches in diameter and a huge trunk is prostrate alongside. In all, 10 stems were seen in a space of 40 or 50 yards and all are cut off at the overlying sandstone, with which they are filled. Sorby was much interested by the discovery that the roots are arranged as are those of trees in Great Britain of to-day—they are almost horizontal on the west side but pressed down on the east, showing that the prevailing winds were the same as now. Platt[79] described a tree rooted in an inferior fireclay with the roots so arranged as to confirm Sorby's conclusions respecting the direction of the winds. W. B. Dawkins, in commenting upon the paper, stated that he had made examination of the tree and that his conclusion was the same with that of Sorby and Platt.

Adamson[80] described a gigantic *Sigillaria* with 8 forked *Stigmaria* roots attached. The area embraced in the ramification of the roots is 826 square feet; it is difficult to conceive of removing this mass by a landslide or on a level area so as to set it down with the stem vertical and the roots outspread in normal position; and the difficulty is increased by the presence of other trees near by. This tree was figured in 1887 by Williamson[81] who says that a larger example was found near that described by Adamson, and that one of the root divisions was traced 37 feet 4 inches to a sharp tip.

[78] H. C. Sorby, "On the Remains of a Fossil Forest in the Coal Measures of Wadsley, near Sheffield," *Quart. Journ. Geol. Soc.*, Vol. XXXI., 1875, pp. 458–460.

[79] S. S. Platt, "Notes on a large Fossil Tree recently found in Shales of the Coal Measures at Sparth Bottoms, Rochdale," *Trans. Manch. Geol. Soc.*, Vol. XXIII., 1895, pp. 65–69.

[80] S. B. Adamson, *Rep. Brit. Assoc. Adv. Sci.* for 1886, p. 628.

[81] W. C. Williamson, "A Monograph on the Morphology and Histology of *Stigmaria ficoides*," *Palæontograph. Soc.*, vol. for 1886, pp. 45, 46, 48, 51, Pl. XV.

He states that 7 smaller but similar examples were found in excavations for a street in Bradford.

Grand'Eury and Goeppert have described many occurrences of *in situ* trees; and the former, in his memoir before the Geological Congress at Paris, gave figures and descriptions of *Calamites* with roots from the joints similar to those found by Sorby. Barrois[82] has reviewed the conditions in a keenly analytical memoir, referring especially to conditions in the Nord basin. His discussion will find place in another connection; it suffices here to note that he has found erect trees only in deposits which have been laid down in shallow water; they are wholly absent from deposits laid down in water deep enough to float the trees.

Not a few writers insist that occurrences of this sort can be explained readily by supposing them to be due to landslides or deluge-like floods. It might suffice to say with Goeppert that the explanation might answer if the instances were few, but that it does not answer because the number of erect trees is so great. But the proposed explanation is wholly unacceptable because the conditions observed do not suggest either landslides or terrific floods.

The White Mountains of New Hampshire have long been celebrated for the extent of landslides. One is typical of all. Perkins[83] described that which took place in the southern part of those mountains after a prolonged heavy rain in October, 1869. The light-colored streak marking its path was visible at a distance of 50 miles. The whole mountain had been covered with a dense growth of spruce. The slide began at 40 rods below the summit, 4,200 feet above tide. It was barely one rod wide at the top and increased little in the first 50 rods, where the slope is between 50 and 60 degrees; but, in the next 100 rods, the width increased rapidly to 25 and 30 rods at 130 rods from the beginning; thence it decreased to 17 at 166 rods. The whole length is nearly 240 rods and the outline is fusiform. Three miles below the termination of the

[82] C. Barrois, "La répartition des arbres debout dans le terrain houiller de Lens et de Lievan," *Ann. Soc. Geol. du Nord.*, Vol. XL., pp. 187–196.

[83] G. H. Perkins, "Notice of a Recent Landslide on Mount Passaconoway," *Amer. Journ. Sci.*, II., Vol. XLIX., 1870, pp. 158–161.

slide, a level clearing through which Mad River flows, was covered with great heaps of logs brought down by the slide and swept away by the freshet attending it. They were broken and shattered, though some were 60 feet long. They were piled up confusedly to a height of 15 or 20 feet, stripped of foliage and most of the smaller branches. Farther up the stream, no trees were visible; they had been buried in the coarse debris of the slide.

The terrific discharge of Lake Mauvoisin has been cited as evidence that blocks of the surface could be transported with standing trees and be deposited in the normal position. Knowledge respecting this great debâcle is derived from the description by Escher von Linth, of which a synopsis was published in English.[84] The Val de Bagnes is drained by the river Dranse, whose progress had been impeded for several years prior to 1818 by blocks of ice and by snow avalanches from the glacier of Getroz. At length the river was dammed and a lake was formed, which became 10,000 to 12,000 feet long, 700 feet wide at top, 100 feet wide at bottom, with an average depth of 200 feet. The content equalled at least 800,000,000 cubic feet. A gallery, 600 feet long, was cut to drain the lake, but this enlarged quickly in the ice, so that before one half of the water had passed off, the dam gave way and the mass of ice, water and débris was precipitated into the valley below. The whole lake was emptied in less than half an hour and the author well says that one cannot describe the violence of the flood. The passage of the water was checked by a narrow gorge, where it tore away a bridge, 90 feet above the preëxisting stream; beyond that, it entered a wider part of the valley, only to be banked by another gorge beyond. Thus passing from one basin to another, it acquired new violence and carried along forests, rocks, houses, barns and the cultivated surface. The flood seemed to contain more débris than water and it moved at the rate of 18 feet per second. The acquisition of these materials made the current more effective and, when it entered the narrow valley leading from Saint Branchier to Martigny, it con-

[84] "Account of the Formation of Lake Mauvoisin by the Descent of a Glacier and of the Inundations of the Val de Bagnes in 1595 and 1818," *Edin. Phil. Journ.*, Vol. I., 1819, pp. 187–191.

tinued its work of destruction until weakened by spreading over the great plain of the Rhone valley. After ravaging Le Bourg and the village of Martigny, it fell with comparative tranquillity into the Rhone, "leaving behind it on the plain of Martigny the wreck of houses and furniture, thousands of trees torn up by the roots and the bodies of men and animals, which it had swept away."

Neither landslide nor vast flood can be invoked for explanation of phenomena such as those described by Adamson, Potonié and Binney. It is incredible that the work of such destructive agents would leave no record except a group of trees resting normally with the roots of one interlaced with the roots of the others. There is no trace of disturbance at any locality mentioned by the observers named or by any others; yet the discoveries by Binney, Hawkshaw, Bowman and Platt are in the same small area, each covers a considerable space and everywhere there is evidence of wholly undisturbed deposition. The evidence that the trees are *in situ* is as strong as it is for Russell's gravel buried forest in Alaska or for the sea-covered forests on the shores of the Baltic and Britain.

The trees *in situ,* the ripple marks, rain and footprints, the evidence of selective action by streams, all go to show that shales were deposited in, at most, shallow water and that great areas of the Appalachian basin, like other regions in which shales occur, were above the area of deposition for prolonged periods.

The Limestones and the Marine Deposits.—Four limestones, with marine fauna, have been discovered in the Warrior coal field of Alabama, all, except possibly the highest, in the New River; Safford discovered a "local bed" of hard crinoidal limestone in his Upper Conglomerate within Grundy county of Tennessee, also New River; M. R. Campbell found a marine fauna in southern West Virginia within the New River and D. White[85] obtained *Spirorbis* and *Naiadites* in the southern anthracite field. The last is possibly brackish water; the others, distinctly marine, show that during the New River salt water occasionally had access, at least locally,

[85] D. White, "Deposition of the Appalachian Pottsville," *Bull. Geol. Soc. Amer.,* Vol. 15, 1904, p. 277.

as far north as New River of West Virginia on the eastern side of the bituminous region.

Evidence of marine conditions here and there in the northern half of the basin becomes distinct early in the Beaver. On the southeast outcrop along New River, West Virginia, one finds a silicious limestone, non-fossiliferous, of which traces appear at localities farther west almost to the Kentucky line. Somewhat higher is the Eagle limestone of I. C. White, black, blocky and, as are also the associated shales, richly fossiliferous. These deposits seem to be unrepresented farther north and to be confined to a narrow area in West Virginia. No trace of limestone or of any marine deposit within the Beaver is known east from the Allegheny mountains; none has been observed within the first three bituminous basins of Maryland, Pennsylvania or West Virginia, unless the Black Flint of the last state belong to the Beaver and not to the Allegheny,—and it is confined to a small area near the Kanawha River; nor is there any along the northern outcrop in Pennsylvania and Ohio. In northern Mercer county of Pennsylvania, 60 miles south from Lake Erie, one is on the northern limit of the Upper and Lower Mercer limestones of I. C. White, which are in the shale mass underlying the Homewood sandstone and are associated frequently with iron ore.

These deposits are persistent southward along the Ohio-Pennsylvania boundary for about 40 miles but they rarely extend eastward from that line to more than 25 miles. The limits of their area are well marked, north, east and south, within Pennsylvania and no trace is found beyond. The upper limestone is of irregular occurrence in Ohio but the lower bed is persistent with, in several counties, its boundaries at east and west thoroughly well defined. It crosses Mahoning, Portage and Summit, but it is wanting in Medina at the west. It is wanting in the panhandle counties of West Virginia and in eastern Ohio to about 40 miles west from the Ohio River. The Lower Mercer is present southward from Portage and Summit in an irregular strip, 30 to 50 miles wide, to Vinton county and it enters the northwest corner of Scioto at about 20 miles north from the Ohio River. The western boundary is reached

at several localities in the northern part of the state, but, for the most part, the present outcrop is east from it as the limestone area seems to follow irregularly the direction of the pre-Beaver valley in which the Sharon sandstone, or latest deposit of the New River, was laid down. For this reason the limestone is found nowhere in Kentucky. The thickness at the north rarely exceeds 5 feet, but it increases southwardly to 10 feet. The Upper Mercer is less persistent than the Lower, but its unexpected appearance at some localities suggests that its area lay farther west. Both limestones are richly fossiliferous, each being at times a mass of shells. They indicate ingress of the sea in a narrow area, probably nowhere exceeding 50 miles in width and reaching northward to within 60 miles of Lake Erie along the Pennsylvania-Ohio line.[86]

The sea again invaded the basin soon after the beginning of the Allegheny, for the Putnam Hill limestone of E. B. Andrews rests on the first coal bed of that formation. It did not reach into Pennsylvania but it is followed easily in Ohio from Mahoning county near the Pennsylvania line to Perry county, where its character so changes that the bed is no longer available as a stratigraphic guide. In much of its extent, this limestone is associated with flint and iron ore and it shows great variation in thickness as well as in composition. Beyond Perry county, its area of deposit lay west from the outcrop and only the iron ore remains to mark its horizon. It carries an abundant marine fauna at most localities. At not far from the Putnam Hill horizon one finds the Kanawha Black Flint which occupies a small area on both sides of the Kanawha River in West Virginia toward the southeastern outcrop. The probabilities are, according to the plant remains, that it belongs lower in the column. This black calcareous rock is embedded in black shale and the mass is rich in marine forms. The area is more than 100 miles east from the eastern limit of the Putnam Hill and Mercer limestones, so that, like the Eagle limestone, it is evidence that the sea had ingress on the eastern side of the bituminous region.

[86] The observations by I. C. White, Newberry, Andrews, M. C. Read, Stevenson, Orton and A. A. Wright are recorded in "Carboniferous of the Appalachian Basin," *Bull. Geol. Soc. Amer.*, Vol. 15, pp. 66–70, 80–86, 89–91.

Not long after deposition of the Putnam Hill, but long enough for deposition of 40 to 80 feet of inorganic materials, the formation of two coal beds and the erosion of broad valleys, another sea invasion is recorded in the Vanport limestone of I. C. White. This underlies in most of its extent an ore deposit, which in the earlier days was so important that the rock below was termed the Ferriferous limestone. Like its predecessors, it is confined to the west side of the basin. A fossiliferous limestone is present in the Lower Allegheny at some places in western Maryland, but one cannot determine whether or not it is contemporaneous with the Vanport, as no fossiliferous limestone has been found at the horizon within 80 miles toward the west or northwest. The Vanport appears to be wanting in the whole of West Virginia as well as in Pennsylvania south from the line of the Ohio River. The deposit is recognized first at about 70 miles north from the West Virginia line and at an equal distance west from the crest of the Allegheny Mountains.

The most easterly locality in Pennsylvania, from which this limestone has been reported, is in Indiana county at 75 miles east from the Ohio line—apparently the tip of a prong; it appears at many places in the next county north, but its distribution indicates that the area is broken into prongs; and this is the mode of occurrence along the northern border where its limits are very well defined. From western Jefferson, the area is continuous to the Ohio line where the bed is 15 to 20 feet thick. The deposit is less regular in Ohio, being represented in many places by fossiliferous shale, calcareous sandstone and occasionally by limestone. These conditions prevail in Mahoning, Columbiana, Stark and western Tuscarawas, the limestone being of frequent occurrence in the last. Thence southward into Elliott county, Kentucky, the limestone with its ore seems to be continuous; beyond that the ore bed is traceable for many miles. The western boundary of the deposit is reached at a few localities in northern Ohio but, for the most part, it is beyond the present outcrop. While the extent of the Vanport in Ohio may have been less than that of the Mercer, its extent in Pennsylvania was far greater. The sea-invasion reached 60 miles farther east into Indiana county and 70 miles farther north into

McKean county on the New York border. The area in Pennsylvania was not less than 3,000 square miles, while that of the Mercer was little more than 500. At the same time, one must keep in mind that the Vanport was not continuous throughout its area; that on the borders it extends in long diverging prongs, terminating in chert or calcareous sandstone. The Vanport was formed at the close of a somewhat rapid submergence, during which many stream valleys were filled with sandstone. Apparently the peculiar mode of occurrence, the variations in structure and composition along the borders were due to the topography; while the conditions in northern Ohio suggest that in that region the water of the estuary was very shallow. In Pennsylvania and in a great part of the Ohio area, this limestone has a rich marine fauna.[87]

The roof shale of the Middle Kittanning coal bed, midway in the Allegheny, contains *Lingula* and *Discina* as far north as Wayne and Stark counties of Ohio. Aside from this, there appears to have been no serious invasion during the Allegheny after the Vanport. There are, it is true, several limestones, but there is no reason to suppose that, excepting the newest of them, they are in any part of marine origin. The Upper Freeport, almost the last Allegheny bed, is the First Fossiliferous limestone of Kentucky, where it has a marine fauna, but, north from the Ohio River, it resembles the others in that the only fossils are minute forms, allied to those usually regarded as freshwater types.

The Uffington shale of I. C. White, the roof of the Upper Freeport coal bed, often yields abundance of plant remains, but at some widely separated localities on the eastern side, in Monongalia and Upshur counties of West Virginia, as well as in Wirt county of the same state, far within the Central area, it has a marine fauna accompanied by fragmentary remains of plants. Whether or not the fauna exists elsewhere in the Central area is unknown, as the horizon is below the surface and the well records are of no service. The distribution of this deposit is without explanation in the present

[87] The observations by I. C. White, W. G. Platt, Chance, Newberry, Orton, Hodge and E. B. Andrews are recorded in "Carboniferous," etc., as above, Vol. 17, 1906, pp. 98–103, 113, 109–113, 116–121, 128.

state of knowledge. Where plant-bearing, this shale resembles the ordinary roof shale, but where carrying remains of animals it is black, somewhat sandy and occasionally somewhat fetid. It recalls conditions described by A. Agassiz as existing in the Pacific ocean between Mexico and the Galapagos islands.

The Uffington shale was followed by the often coarse and massive Mahoning sandstone, containing one or more coal beds of considerable extent, and that in turn was succeeded by a coal bed underlying the Brush Creek limestone of I. C. White, the Black Fossiliferous limestone of the early Pennsylvania reports. This dark, almost black rock, enclosed in black shales, is the first limestone which crossed the bituminous region and reached the line of the Allegheny Mountains—it is recognized without doubt in western Maryland. The deposit is wanting along practically the whole eastern outcrop in West Virginia and most probably throughout the interior of that state, for it has not been found under the great anticline in Wirt county and black shale, at this horizon, is not recorded by the drillers of oil wells. It is persistent in western Pennsylvania, which it enters from Preston county of Virginia and Garrett of Maryland. The area, narrow at first, widens to 15 or 20 miles farther north and retains that width to the Ohio line. Thence it is present for 40 or 50 miles southwestward into Jefferson county of Ohio, beyond which it seems to be wanting for about 30 miles. But it reappears and is followed easily into Muskingum county, beyond which no trace exists, the horizon being exposed at very many places. The gap beyond Jefferson county is evidently due to erosion, but there is no reason to suppose that the limestone ever existed south from Muskingum county. The limestone and shales are crowded with a marine fauna and the conditions indicate that it was deposited in an estuary opening at the east.[88]

The Cambridge limestone of E. B. Andrews is at a little distance higher in the Conemaugh column. A marine limestone, very near this horizon, is in western Maryland, but that locality is more than 75 miles east from the nearest outcrop of the Cambridge; its rela-

[88] For the observations by Martin, I. C. White, Newberry, Stevenson, and Orton, see "Carboniferous," etc., as above, pp. 167–189.

tions are with the eastern side. The most easterly point in Pennsylvania, at which the Cambridge can be recognized with certainty, is almost 60 miles east from the Ohio line and about 70 miles north from that of West Virginia. Thence it is persistent into Ohio. The direction of the area is almost westward in Pennsylvania but in Ohio it becomes west of south, and the bed is easily followed across that state and Kentucky to the last exposure of its horizon. In southern Ohio and in Kentucky it extends eastward beyond any predecessor and at the south it reaches into West Virginia; but it is absent under the Wirt anticline in both Ohio and West Virginia. In Pennsylvania, its area is far less than that of the Vanport and the thickness rarely attains 8 feet. The distribution of the deposit indicates a return to the earlier condition, as this is confined to the west side. The abundant fauna is marine.[89]

Midway in the Conemaugh is the remarkable deposit, the Ames limestone of E. B. Andrews, the Green Fossiliferous limestone of the early Pennsylvania reports. It overlies the Pittsburgh reds, from which it is separated in extensive areas by the Harlem coal bed and the associated shales. It has not been discovered anywhere east from the Allegheny Mountains unless one accept as its equivalent the Mill Creek limestone of the Northern Anthracite field, which certainly is in the Conemaugh, possibly not far from the Ames horizon. The Ames is thin, seldom more than 4 feet, and is more or less argillaceous, especially on the eastern side. The color is bluish green, thoroughly characteristic in most of the area, so that the bed is a most important stratigraphic guide. Along the eastern border it has been recognized positively to 75 miles south from the Pennsylvania line; it is present in western Maryland and southwestern Pennsylvania, wherever its horizon is exposed; it is equally persistent in Ohio and Kentucky, being the Fourth Fossiliferous limestone in the latter state. It extends on the west side to the middle line of the basin, being exposed under the Wirt anticline in both Ohio and West Virginia. It was deposited in an area

[89] For observations by Martin, I. C. White, W. G. Platt, Stevenson, Orton, Andrews, Lovejoy and Bownocker, see "Carboniferous," etc., as above, pp. 168, 175–180, 183–194, 197–201.

of not less than 16,000 miles, possibly much more, since no information can be derived from the ordinary well records. This widely extended deposit was certainly not continuous with the Mill Creek limestone of the Northern field; the nearest outcrops of the two rocks are separated by 150 miles, including a part of the bituminous region in which the Ames never existed. The fauna is marine throughout, even on the extreme western border in Meigs county of Ohio where Condit[90] found the limestone impure, sandy, ferruginous, conglomeratic with pebbles of sandstone and with sun cracks on its upper surface. This marine invasion, affecting the greater part of the Conemaugh area, followed the deposition of the fine muds known as the Pittsburgh reds and was succeeded by the Washington reds. Even where the reds are absent, the limestone is usually between deposits of fine grain. Marine conditions preceded it and continued after it; shales equivalent to the Pittsburgh reds carry a marine fauna at some localities and, in Pennsylvania, marine forms persisted up to 50 feet above the limestone.[91]

The only limestones in the anthracite region are in the northern field, where they were seen by Ashburner. Three of them are without fossils but the fourth, the Mill Creek at 688 feet above the Baltimore coal bed and one foot thick, has a marine fauna. A black shale at Dundee, in the same field and 250 feet above the limestone, has the same assemblage of fossils. A peculiar feature of this fauna is that it includes some forms unknown elsewhere in the Appalachian basin, though abundant in the coal area beyond Cincinnatia—which seems to indicate communication by some other way than that at the southwest.

Marine invasions practically ceased with the Ames episode: there are other beds of limestone in the upper part of the Conemaugh but they appear to be at least non-marine.

Five limestones have been recognized in the Monongahela, but they are confined to a small space in southwestern Pennsylvania and

[90] D. D. Condit, letter of April 24, 1912. The locality is Sec. 10, Salem township, Meigs county.

[91] The observations by I. C. White, Stevenson, W. G. Platt, Martin, Newberry, Hodge and Andrews are recorded in "Carboniferous," etc., as above, pp. 167–202, 208, 211, 215.

immediately adjacent parts of Ohio and West Virginia, in all less than one fifth of the present area of the formation. The deposits are especially important in Pennsylvania between the Monongahela and Ohio Rivers, perhaps 2,000 square miles, but they disappear rapidly in all directions. The extreme development is near Wheeling on the Ohio, where one finds 154 feet of limestone in 190 feet of measures; but nearly the same thickness is shown near the Monongahela, where, however, the section is longer, as it has sandstones and shales which are wanting at Wheeling. These deposits vary from almost pure limestone to calcareous shale, and in much of the area they are in layers one to 4 feet thick, separated by much thinner layers of calcareous shale. Their appearance is so characteristic that one familiar with them in any locality could hardly mistake Monongahela limestones elsewhere for those of any earlier formation. Animal remains are confined to a few types. Minute forms, resembling the ostracoids found in the upper limestones of the Conemaugh, are abundant at many places. Teeth of *Helodus* and a spine of *Ctenacanthus marshii* have been collected from midway in the formation within Washington county of Pennsylvania; the fourth limestone is rich in *Naiadites* near Uniontown, Pennsylvania, and a blue shale near Morgantown, West Virginia, contains abundance of *Solenomya*. The fish remains are the same with those which abound in the marine limestones of Illinois, but these marine forms are evidence of sea invasions so brief as to have no significance, for they are unaccompanied by marine molluscs. All the features indicate that the Monongahela limestones are, in greatest part, of freshwater origin.

The Washington formation has six limestones, confined practically to Greene and Washington counties of Pennsylvania, all, except one, disappearing quickly in each direction. They resemble those of the Monongahela, some being covered with similar forms, thought to be of freshwater types. Larger fossils are very rare. I. C. White obtained from a black shale in the upper portion scales of *Rhizodus* and other fishes, which are most probably freshwater in their relations, as the same genera occur in a cannel layer at Linton, Ohio. The Greene formation has many limestones within

southwestern Pennsylvania, but apparently most of them are mere lenses and few of them can be regarded as definite members of the section, though they are the striking feature in the lower half of the formation. The Nineveh limestone, however, is persistent, having been recognized along a line of more than 100 miles, and is 22 feet thick at its last outcrop in West Virginia—strangely persistent in an area where every other bed in the column is changeable. Although the beds have small extent, the quantity of limestone in the Greene is very great. Fossils are rare; minute forms, mostly ostracoids, occur in many beds and occasionally one finds in the shales a form resembling *Naiadites*. Some of the more argillaceous limestones contain much finely comminuted vegetable matter.

The composition and structure as well as the fossils in many limestones above the Ames horizon have led to the belief that they were deposited in freshwater basins; and evidence of like character is not wanting in some of the Allegheny limestones.

I. C. White[92] found that the Upper and Lower Freeport limestones are very often brecciated in some of the layers and concluded that they had been deposited as muds in inland lakes—conclusion very like that of E. B. Andrews presented in 1873. Ostracoids are abundant in the Upper Freeport. Farther south in Pennsylvania, the brecciated limestones appear toward the end of the Conemaugh and the fossils are ostracoids along with forms resembling *Spirorbis*. The limestones of the Monongahela, Washington and Greene are brecciated at very many localities and some of them rarely show normal structure. Ostracoids and *Spirorbis*-like forms are extremely abundant in some.[93] Hyde's[94] observations in Ohio prove that conditions are the same in that state. A limestone in Noble county, below the Ames, about 10 feet thick, has an irregular top owing to erosion prior to deposition of the overlying sandstone. The upper surface is mud-cracked and the cracks are filled with

[92] I. C. White, Sec. Geol. Surv. Penn., Rep. Q, 1878, contains numerous illustrations; Rep. Q2, 1879, p. 220.

[93] J. J. Stevenson, Sec. Geol. Surv. Penn., Rep. K, many references.

[94] J. E. Hyde, "Desiccation Conglomerates," *Amer. Journ. Sci.*, IV., Vol. XXV., 1908, pp. 400–408; letter of January 12, 1912.

shale. Some layers are crowded with tubes resembling those of annelids. The overlying sandstone contains limestone fragments in the lower portion. A conglomerate limestone in Belmont county, and very near the top of the Conemaugh, shows shrinkage in the limestone fragments. The Monongahela limestones in the same county vary from hard to soft, often becoming calcareous shale. Shrinkage cracks are so numerous at times as to give a brecciated structure. These limestones contain several species of minute ostracoids which are very abundant, and in some beds one species of ostracoid is well represented. These cover the bedding planes and are shown especially well on sun-cracked surfaces Conglomerate layers are frequent, varying in thickness from half an inch to 3 or 4 inches, and the fragments are from pea-size to several inches in diameter. Hyde thinks the deposits are of freshwater origin like the freshwater limestones in some of the western states and he conceives that they represent the calcareous mud laid down in probably shallow bodies of water. During the summer, the water was evaporated and the ostracoids with the *Spirorbes* were left on the muddy surface, which, exposed to the heat, became sun-cracked. A similar explanation was suggested by Haast[95] who, in describing some Tertiary marls, says that they must have been "left high and dry, exposed to the effects of a powerful sun, is well shown by numerous cracks in the clay marls, which are several inches wide and deep."

Brecciated limestones have been reported frequently from other lands and the explanations offered are not wholly concordant. Roeder[96] found in the Lancashire field a succession of red shales and clays with thin coals and two limestones, in all somewhat less than 900 feet thick. At Slade lane he saw 206 feet of measures, mostly red, green or variegated shales with in all 21 feet 4 inches of limestone. Some of the limestones are brecciated locally and the passage from breccia to the normal structure is gradual. The frag-

[95] J. Haast, "Report on Geology of the Malvern Hills, Canterbury," Rep. Geol. Surv. N. Z., 1872, pp. 63, 64.

[96] C. Roeder, "Notes on the Upper Coal Measures at Slade Lane, Burnage," *Trans. Manch. Geol. Soc.*, Vol. XXI., 1890, separate, pp. 7–22.

ments are from pinhead to 2 inches and the larger ones are angular, the edges at times jagged; the smaller pieces are more rounded. In weathering, the fragments give way first, which leads Roeder to suppose that they must have suffered from subaerial exposure before entombment. He regards the condition as proof of occasional elevation and exposure, when older limestones were broken up and either transported or left *in situ*. Additional evidence in favor of this conclusion was found in his discovery of angular fragments of the *Spirorbis* limestone in sandstone at Ardwich. He cites Hull and Williamson to show the wide occurrence of brecciated limestone in England.

De Dorlodot[97] discussed the great breccia in the upper part of the Carboniferous within the Franco-Belgian basin. He says that some geologists have supposed it to be due to dynamic action, but he believes it sedimentary, due to destructive attack by waves and the rapid accumulation of the products. The elements vary much in size and the paste, filling spaces between large and small blocks, is itself partly limestone. The fragments, large and small, have their angles but slightly rounded. In any event, they could not have come from far.

Stainier[98] took vigorous exception to de Dorlodot's explanation, because nothing of the sort is known in actual times. The supposed conditions exist at many places along the coast of Great Britain, but no breccia forms. If, by change in conditions, the shallow Carboniferous sea should be dried up completely, the exposed limestone would be a desert surface. The contrast in temperature would break up the rock and give material for the breccia. When the sea returned and invaded the area, it would sort the materials. The coarse blocks would be moved little, the less coarse, farther; by insensible gradation one passes to the compact limestone which, east from Namur, occupies the breccia horizon.

It is difficult to believe that the brecciation was caused by ex-

[97] H. de Dorlodot, "Sur l'origine de la grande brèche Viséene," *Bull. Soc. Belge de Geol.*, Vol. XXII., 1908, Mem., pp. 29–38.

[98] X. Stainier, "Du mode de formation de la grande brèche du Carbonifere," *Bull. Soc. Belge de Geol.*, Vol. XXIV., 1910, P. V., pp. 188–196.

posure after the limestone had become consolidated; the features in most cases are those observed where a moist material, still soft, is exposed to the air; the brecciation is that of cracking due to loss of moisture. Haast's explanation, more or less modified by later students, is evidently the one most closely related to the facts.

Perhaps some reader may hesitate to believe that limestones as thick as those of western Pennsylvania can be of freshwater origin; but they are not greater than some recent marl deposits within the United States. Davis[99] has discussed the whole subject showing the mode in which the material accumulates and its relation to peat deposits. D. J. Hale, in the same volume, described many Michigan deposits, 20 to 47 feet thick. Blatchley and Ashley[100] have shown that conditions are the same in Indiana as in Michigan. They are convinced that the supply of calcareous matter was ample in later Coal Measures times, for limestones must have cropped out in extensive areas and the springs in much of the region must have been charged with dissolved limestone. But both the Appalachian limestones and the western marls are insignificant when compared with those of the Tertiary lignite area of l'Aude in France.[101] The section at Cavonetti shows at top a freshwater limestone, nearly 80 meters thick. Some of its beds are rich in river shells and others are equally rich in *Lymnæa* and *Planorbis,* which are found also in the shales and in the lignite. A similar limestone, 10 to 15 meters thick, is lower in the section and the lowest member exposed is of the same type.

The presence of *Spirorbis* has been regarded by some as an objection to acceptance of freshwater origin for the limestones, for beyond all doubt that form is related to marine types. It occurs throughout the Coal Measures column, sometimes in deposits which are certainly marine and at other times in deposits which are dis-

[99] C. A. Davis, "A Contribution to the Natural History of Marl," Geol. Surv. Mich., Vol. VIII., Pt. III., 1903, pp. 65–96.

[100] W. S. Blatchley and G. H. Ashley, "The Lakes of Northern Indiana and their Associated Marl Deposits," Twenty-fifth Ann. Rep. Geol. Surv. Ind., 1901.

[101] (M) de Serres, "Observations géologiques sur le Département de l'Aude," *Soc. des Sci. Lille,* 1835, pp. 453–455.

tinctly not marine. The best summary of the conditions was given by Barrois,[102] who was led by the apparently contradictory modes of occurrence to make thorough investigation of the whole subject. Some of his conclusions will find place in another connection but others are of interest here. He found *Spirorbis* shells attached to living plants, to plant débris, to brackish and even to essentially salt water animals. In the larval condition, the type is free but in the adult, fixed. It is allied to *Vermetus* and *Spirorbis* of the present time, all marine. To reconcile the existence of such forms on plants essentially terrestrial, one must admit that the original Carboniferous *Spirorbis* lived fixed on marine shells; that the descendants became habituated to brackish water, where they attached themselves to *Carbonicola;* and at last to fresh water, where they became fixed on ferns. It is very evident that the conditions noted by Barrois exist in the Appalachian basin, so that the presence of *Spirorbis* cannot be regarded as evidence for or against any hypothesis respecting the character of the water.

It is quite possible that the occurrence of *Naiadites* may be evidence of brackish water invasions.

Reference has been made to very dark carbonaceous or bituminous limestones, of which the Brush Creek may be taken as type. They are not numerous. Their fauna is marine, they are often fetid and, at times, have some vegetable matter. The Brush Creek limestone, as has been shown, occupies a long narrow area, bordered by shales and sandstones and, at some localities in both Pennsylvania and Ohio, it suffered severely from erosion prior to deposition of the overlying rock. De Dorlodot[103] has discussed the origin of sapropelic limestones and his conclusions seem to require examination at this point. Some crushed polyps, exhibited at a meeting of the Geological Society, were in a gangue which had undergone slow compression, such as that which Potonié had recognized as characterizing sapropelian muds. A. Renier had accepted sapro-

[102] C. Barrois, "Sur les Spirobes du Terrain Houiller de Bruay (Pas-de-Calais)," *Ann. Soc. Geol. du Nord.*, Vol. XXXIII., 1904, pp. 50 et seq.

[103] H. de Dorlodot, "Sur les conditions de dépot des marbres noirs dinantiens et des sapropelites marines en général." *Bull. Soc. Belge de Geol.*, Vol. XXV., 1911, P. V., pp. 146 et seq.

pelian origin for the black limestone of Hun and F. Kaisin had done the same for the Dinant marbles. De Dorlodot agrees with Renier that the limestone is marine but dissents from the opinion that it is a coast deposit. The conditions and stratigraphical relations had led him to believe that it was deposited far from shore, for the deposits are not local, they are extensive and their lithological character suggests deep-sea origin.

According to de Dorlodot, Renier's decision in favor of shore deposit depends upon the presence of terrestrial plants and of sapropelic matter in the limestone; but presence of remains of terrestrial plants is irrelevant, for A. Agassiz found them far from shore and in deep water off the Pacific coast as well as in the Gulf of Mexico. Sapropel deposits can be formed along coasts only in lagoons or in bays protected against movement of the waves. Proximity to the coast is not possible, for action of the waves would cause continuous oxygenation of the water. The deep sea would be most favorable to accumulation. He supports his opinion by reference to carbonaceous shales of the Toarcien, asserting that their geographical extent is proof that they were not deposited in isolated bays, while their fauna proves deposit in the maximum of immersion—and those shales contain remains of land plants. The fact that deep sea soundings in our day show no sapropelian deposits is not final. The problem is not to explain why the old marine rocks are so rich in kaustobiolithic materials, but why modern deep sea deposits are so poor. The problem may be stated in another way. How is aerobian life possible in great depths of the ocean so as to cause destruction of the organic matter which the plankton must afford? This is explained by the bottom-creep of oxygenated water from the poles; in the Black sea, which is beyond the influence of that creep, there are only anaerobic organisms in its depths. Sapropelic character does not prove shore origin—it rather tends to establish and at times to demonstrate deposition at distance from the shore and at great depths. De Dorlodot believes that the limestones under consideration were deposited far from the coast and in calm water.

It is difficult to discover the force of this reasoning and equally

difficult to understand the bearing of some of the arguments upon others. That from geographical extent is unimportant for the Brush creek limestone has been traced 150 miles and it must have had a notable area in the now eroded region at the east. Nor does it seem essential to deposition of sapropel that the water be calm. Potonié has told of extensive lakes in Germany, formerly navigable but now choked with sapropel. The surface of navigable lakes, great or small, is apt to be churned into waves. No reason can be assigned why the Frische Haff, at the mouth of the Vistula, may not be filled with sapropel, provided conditions remain as now. The presence of fragments of land plants is not of itself final evidence of deposit in shallow water or on an offshore area; but the discoveries by A. Agassiz hardly relate themselves to the matter, for he did not report the presence of sapropel material in mud holding fragments of rotten wood, though the region is one as favorable to accumulating such material according to de Dorlodot's conception as one can imagine. The arctic creep must be at its minimum in the Gulf of Mexico. One may hardly refrain from suggesting that de Dorlodot has not conceived the problem fairly. Unquestionably the absence of kaustobiolithic materials from deep sea deposits of this day is as perplexing as interesting and the explanation offered by that author may or may not be correct. But that is not the serious problem, for most of the Coal Measures marine limestones are as free from sapropel as are the present deep-sea limestones, so that conditions then were very much like those of this time. The assumption throughout the discussion is that the marine fauna of the limestone indicates very considerable depth of water, the maximum of immersion. Even this is open to question. True, it is in accord with the prevailing opinion, which, having been unchallenged for a long period, has become, for many, one of the fundamental pillars of geology. Studies by palæontologists in the Appalachian areas lend no support to the belief that deep water covered the Appalachian basin during the Palæozoic and the stratigrapher hails their conclusions with gratification, as they coincide with his own. These conclusions and the arguments supporting them will be found on a later page. The arguments are applicable equally to conditions in other lands.

The use of the term currents to explain local conditions is apt to be misleading. There is no good reason for supposing that there were any currents in the Appalachian basin. The close succession of often coarse sandstones upon marine limestones, even upon sapropelic limestone, shows that the deposits were near a shore.

A review of the conditions leads to conclusions the same as those suggested by deposits of other materials. The marine limestones are local, are in areas which, for the most part, can be determined closely. Those of the earlier formations are found on both sides of the Alleghenia ridge, but the localities, at which observations have been made, are too widely separated to admit of an attempt to determine their relations. The Beaver and Allegheny limestones, however, have been traced in detail. On the western side, within the Ohio basin (of Schuchert), they followed in a general way the direction of the pre-Beaver valley in Ohio but as they approached the Pennsylvania line, they turn eastward into that state. This variation becomes notable in the Vanport, which seems to have followed rather closely in Pennsylvania the lines of valleys eroded during the immediately preceding times. There can be no question that the early drainage line, established prior to Beaver time, persisted until the middle of the Allegheny and that it determined the area of sea-invasion, as the old river valleys along the Atlantic coast have done in recent times. The extent of the limestones, though they follow the same line in great part, shows that the estuaries, due to drowning of the valleys, were not of equal length. When one examines the conditions on the eastern side, he finds that, in the Beaver and Allegheny, the marine limestones occur within a small area in West Virginia. Erosion has removed the Pennsylvanian from a great expanse on the eastern side so that the relations of these limestones cannot be determined beyond the present exposures, but the deposits seem to mark the upper portion of successive estuaries along the same general course. The sea-invasion on this side may not have reached so far north as on the western.

In the early Conemaugh, the conditions were somewhat different.

The long serpentine course of the Brush Creek limestone from Maryland to central Ohio shows that, while there had been no great topographical change and the whole area was still lowland, there had been enough change during deposit of the underlying sandstone to make possible, by slight submergence, a broad, continuous drowned valley across nearly the whole bituminous region,—from very near the eastern outcrop westward to the line of the pre-Beaver valley. This depression did not affect the southwestern part of the region as there is nothing there answering to the Brush Creek; the invasion was from the east. But during the next interval, the earlier conditions were restored and one finds the Cambridge limestone following approximately the course of the Vanport in Pennsylvania, Ohio and Kentucky, though reaching farther eastward in the latter states. But at about the same time, there was a new invasion on the eastern side along the line of Brush Creek estuary, for a marine limestone is present in western Maryland while farther west near the Monongahela River in West Virginia, there is a non-fossiliferous limestone, which may represent the shore phase of the same deposit.

The Cambridge limestone marks the temporary culmination of a long continued subsidence which brought a constantly widening area on the west side to sea-level and eventually below it. That area continued to widen eastward and reached its maximum when the Ames limestone was deposited. Peneplanation of the bituminous region had become far advanced; for a long period only fine material had been brought down by the streams and a very great part of the region had become converted into mud flats through which the streams meandered in shifting channels, sorting the fine clays and sands. The rivers must have emptied into estuaries around the border for marine conditions existed as far north as the southern line of Pennsylvania just prior to the Ames. Limestone deposition began first at the west, the thickness and purity of the rock being best marked in Ohio, and advanced east and northeast until the bed covered a great part of the bituminous region. The efflux of the cleaner water was abrupt, but the limestone is followed by fine deposits at most localities and it was not until 70 feet of shales had been laid down in much of the region that the normal conditions were restored. It is possible that the 70 feet of muds, in which

there is evidence of marine life, may be the measure of the extreme possible depth at which the Ames limestone was deposited. Indeed one is tempted, in view of conditions observed on islands in mid ocean, to suggest that the abrupt appearance of muds above the Ames might be regarded as evidence that the limestone was deposited in very shallow but very clean water; and the temptation is the stronger, because stream-sorting appears in the arrangement of materials composing the overlying shale.

Were these limestones deposited in deep water? The testimony of the fossil remains in answer to this question will be examined on a succeeding page; but there are several matters to be considered here. In some cases, the limestones can be followed to their disappearance. The Vanport limestone in Pennsylvania ends in long prongs within Pennsylvania, gradually passing into sandstone, débris from the sides of the valleys in which the limestone terminates. And fossils continue after the change has begun. The western edge of the Ames limestone was reached by Condit in Meigs county of Ohio, where that rock, still fossiliferous, is rippled and is conglomerate with quartz pebbles. This condition is not unknown in other limestones of the Carboniferous; if verbal statements of geologists, who cannot recall localities, may be accepted, the condition is familiar. The writer is indebted to Butts[104] for specific instances in earlier formations. Shrinkage cracks and wave marks are abundant in marine fossiliferous rocks of Stones River and Black River age in southern Tennessee, where the deposits, he is convinced, are of shallow water origin. In the Cahaba valley of Alabama, on the border between the Bessemer and Montevallo quadrangles, he discovered at the base of the Stones River (Chazyan) limestone, a pebbly bed, which was examined in an area of several square miles. At one locality, the pebbles are comparatively few and occur in a layer never more than 2 feet thick; but elsewhere the vertical distribution is much greater, becoming 20 feet, in which fragments are abundant, while small pebbles occur throughout the higher portion of the bed. The pebbles are of quartz, quartzite and chert, varying in size from three fourths of an inch down. Many are

[104] C. Butts, letter of June 21, 1912.

well rounded, but those which are angular or subangular are quite as abundant. *Maclurea magna* and a considerable number of other forms are present in the limestone containing the pebbles. This locality must have been very near a shore line; there is no evidence to suggest that the shore was precipitous and one must agree with Butts that deposition in shallow water is indicated, although, according to accepted doctrine, the fossils suggest deep water. The presence of fossils in the Chazyan limestones as well as in the Ames and Vanport, where the rock is changing into merely calcareous sandstone, makes clear that the presence of marine fossils is not to be taken as final evidence of deposition in deep water.

The Testimony of the Fossils.—There are few fossiliferous horizons in the Appalachian basin and collections have been made at not many localities. But, if one bear in mind that the areas of marine deposits are comparatively insignificant, the number of collections will appear sufficient.

A systematic collection of Mercer forms was made in the Zanesville-Newark region of Ohio[105] and some notes respecting the fauna of the same horizon in Pennsylvania were given by I. C. White. In the Ohio area there were obtained species as follows: One crinoid, 1 coral, 5 bryozoans, 3 inarticulated brachiopods, 13 articulated brachiopods, 40 pelecypods, 14 gastropods and 2 cephalopods. Raymond[106] has given a list of forms collected by him from the Vanport at several localities in Beaver county of Pennsylvania; it shows 3 corals, 2 bryozoans, one inarticulated brachiopod, 14 articulated brachiopods, 3 pelecypods, 20 gastropods and 3 cephalopods. I. C. White added to this list from Lawrence county 2 crinoids, 1 articulated brachiopod, 7 pelecypods, 5 gastropods and 1 cephalopod. Twenty-three species are common to the Mercer and Vanport in these lists. Probably the Vanport list is incomplete, as a consider-

[105] Clara G. Mark, "The Mercer Limestone and its Associated Rocks in the Zanesville-Newark Region," *Bull. Sci. Labor. of Denison Univ.*, Vol. XVI., 1911, pp. 267–314; I. C. White, Sec. Geol. Surv. Penn., Rep. Q, p. 68; Rep. Q2, p. 61.

[106] P. E. Raymond, "A Preliminary List of the Fauna of the Allegheny and Conemaugh Series in Western Pennsylvania," Topog. and Geol. Surv. [of Penn.], 1911, pp. 83, 84.

able number of the Mercer forms are not recorded, though they have been found in the Conemaugh of Pennsylvania and West Virginia. It is equally probable that the Mercer list is local only, as some forms mentioned in the Palæontology of Ohio are not given.

The first deposit of the Conemaugh is the Uffington shale, which is rich in fossils at some places within northern West Virginia. The important list is that by Meek[107] of forms collected at Morgantown, a few miles south from the Pennsylvania line. There are 4 articulated brachiopods, 8 pelecypods, 11 gastropods, 3 cephalopods, to which Stevenson in later collections added 1 coral, 2 crinoids, 4 pelecypods and 3 cephalopods. The rock is a black shale, more or less ferruginous, the conditions being very different from those of the Vanport and Mercer, yet, in this collection of 26 species made at an exposure of about 25 square feet, there are 14 species in common with the Vanport and 12 with the Mercer. The Brush Creek limestone and associated shales are separated from the Uffington below by the Brush Creek coal and the Mahoning sandstone. Lists from Pennsylvania have been given by Raymond and White and a brief list of forms collected in western Maryland has been published by Martin.[108] The list by Raymond contains 1 coral, 1 inarticulated brachiopod (*Lingula*), 12 articulated brachiopods, 9 pelecypods, 15 gastropods, 5 cephalopods. To these, White adds one pelecypod and Martin adds a crinoid and an articulated brachiopod. Thirteen species are in common with the Mercer and 16 with the Vanport. Omitting the Cambridge, to avoid repetition, one comes to the Ames limestone, which is actually continuous over a greater area than that of any other deposit in the whole column. Raymond's[109] list from five localities on the Pennsylvania railroad, east from Pittsburgh, contains 1 coral, 2 inarticulated brachiopods, 15 articulated brachiopods, 6 pelecypods, 10 gastropods and 4 cephalopods. The inarticulate brachiopods and the pelecypods are rare. Stevenson gave lists

[107] F. B. Meek, "Lists of Carboniferous Fossils from West Virginia," *Third Rep. Regents of W. Va. Univ.*, 1871, pp. 68–70.

[108] P. E. Raymond, loc. cit., pp. 85–87; I. C. White, Rep. Q, p. 34; G. C. Martin, West Va. Geol. Surv., Vol. II., 1903, pp. 280, 281.

[109] P. E. Raymond, loc. cit., pp. 89–92; J. J. Stevenson, Ohio Geol. Surv., Vol. III., 1879, pp. 207, 223.

of forms occurring in Guernsey and Harrison counties of Ohio, where the rock is a fairly good limestone. He found 2 corals, 1 crinoid, 1 inarticulated brachiopod, 15 articulated brachiopods, 2 pelecypods, 7 gastropods and 1 cephalopod. Condit in 1909 published a list from Meigs county, Ohio, which adds two species of articulated brachiopods. Meek's list from near Morgantown is in contrast with that just given, for it shows one species of inarticulated brachiopods, 10 articulated, 12 pelecypods, 7 gastropods, 2 cephalopods, to which Stevenson at a later date added one articulated brachiopod, 6 pelecypods and one gastropod. The contrast is due to the fact that the collection, studied by Meek, was made at a locality where the Ames limestone is obscured in a mass of fossiliferous shales extending downward into the horizon of the Pittsburgh reds. At a mile north, the limestone is distinct and has no pelecypods except *Myalina* and *Aviculopecten*. In comparing these lists with those from earlier deposits, one finds 23 species in common with the Vanport and 24 with the Mercer. The Ames limestone is succeeded in Pennsylvania by shales, at times 70 to 80 feet thick, in which Raymond found marine forms at several levels. They are not abundant, but 2 species of articulated brachiopods, 6 of pelecypods and one cephalopod were recognized and an *Orbiculoidea* was found near the top of the deposit at 75 miles east from Pittsburgh.

It would seem that distribution of the organic types depends often upon the character of the rock. Miss Mack observed that pelecypods are more abundant in the shaly layers and brachiopods are more abundant in the purer limestone. Raymond's lists indicate that brachiopods are very numerous in his Vanport localities, where the limestone is good; it may be that, where White obtained so many pelecypods, the limestone is broken by calcareous shale. The Ames limestone is comparatively pure where Raymond's collections were made and in Ohio it is a good limestone; pelecypods are very rare —6 species are recorded but individuals are very few. Near Morgantown, West Virginia, the Ames yields no pelecypods except *Myalina* and *Aviculopecten*, whereas pelecypods and gastropods are abundant in the associated shale, the latter, at times, making up the greater part of the mass. Brachiopods are less common in these

shales, but they are of the same species as in the overlying limestone and of equal size.

The lists, as has been said, are local; they do not suffice for comparison of faunas at the several horizons; but that is unimportant here. Each locality has been examined with such care as to give a just conception of the manner in which the several groups of organisms occur. It should be kept in mind that fossiliferous beds are not only fewer in number within the Appalachian Pennsylvanian than in the region west from Cincinnatia, but also very much less prolific in species and less commonly so prodigal in individuals. These features suggest to the paleontologist that marine conditions in the Appalachian basin were abnormal.

The cœlenterates give no information respecting the conditions. Only two species of coral have been found and one of them has no preference for limestone over shale, individuals being equally abundant in both. One of the crinoids has a similar distribution.

Few species of bryozoans have been reported but these abound at several horizons. They are found in pure and impure limestones as well as in shales containing very little calcareous matter. They are characteristic of somewhat sandy shales in the Waverly of northern Ohio. Ulrich[110] says that bryozoans of recent time flourish best in water depositing slightly argillaceous limestone—relatively quiet water—and at depths little beyond the zone of violent wave action. The habits of these animals seem to justify the conclusion that the limestones and other beds in which they abound, the Mercer, Vanport and Cambridge, were deposited in comparatively shallow water, probably less than 100 feet deep; and this conclusion is strengthened by the fact that in some localities the area of those limestones was so restricted that violent wave action would be hardly possible.

The brachiopods, at first glance, are less definite. According to Schuchert,[111] among recent species of inarticulated brachiopods 24 live between high tide and 90 feet; 7 between 90 and 600 feet, and only one at great depths. *Lingula* and *Discina* are unknown below 90 feet but *Crania* and *Discinisca* occur at greater depth. The inarticulated forms have changed comparatively little in character since

[110] E. O. Ulrich, *Bull. Geol. Soc. Amer.*, Vol. 22, 1911, p. 252.
[111] C. Schuchert, *Bull. Geol. Soc. Amer.*, Vol. 22, 1911, pp. 258–275.

their first appearance and, in all probability, as little in their habits. For the most part, they cling closely to the strand in recent times. Articulated brachiopods of the present day require deeper water and 84 of the living 129 species belong between 90 and 600 feet. Rhynchonellids are never found in shallow water; but this was not always the condition, for in the older rocks they often occur abundantly with thick-shelled lingulids in coarse sandstones and mud beds. The terebratulids range from between tides downward. Of all living brachiopods, 81 per cent. are bound to shallow waters, 7 per cent. are found in the deeper waters of continental shelves and only 11 per cent. occur at greater depths.

Applying Schuchert's results to the Appalachian basin, one finds that *Lingula* and *Orbiculoidea* (*Discina* of authors) are common in the dark roof shale of the Middle Kittanning coal bed of Ohio and that *Lingula* is found in several roof shales within Kentucky. It is present at the Brush Creek horizon. *Orbiculoidea* is reported from the Mercer and the Ames, one species being common to both, and the same genus has been obtained from the upper part of the muds and shales following the Ames. These forms are not numerous in the limestones but they abound in some shales. The individuals are seldom more than five eighths of an inch long but that size is excelled only by forms in coarse rocks. Of the articulated brachiopods, the rhynchonellids, which now prefer deep cold water, and the terebratulids, most of which now inhabit the deeper shallow zone, are feebly represented in the Pennsylvanian—perhaps because these brachiopods were little differentiated at that time. Of the other types, practically all belong to families now extinct and one must determine their habits by the record which they have left in the rocks. The productids attained noteworthy size in the later Devonian coarse sandstones, where they are associated often with heavy-shelled *Lingula* or *Discina*. They are abundant in both the pure and the muddy limestones of the Maxville. Eight species of *Productus* are reported from the limestones and shales of the Pennsylvanian within the bituminous region, one being common to all the lists, 2 to four of them, 2 to three, two belonging to the Conemaugh and one being confined to the Vanport. Five species are found in limestone and shale alike and two are abundant in shale

which contains only a trace of calcareous matter. The Spirifers are represented by two species, one of which is in shale as well as limestone and its size is the same in both. Sandstones with marine forms seem to be few in the Appalachian basin and the fossils are rare; but such sandstones are numerous in the Devonian of that basin. Spirifers of the later type attain great size in the coarse Oriskany sandstone where they are associated with huge *Discinæ;* while in the later Devonian they are present in the coarser beds of the Chemung, often appearing in great numbers. The athyrids are the same throughout, whether the rock be limestone or shale. A few of the Pennsylvanian brachiopods occur only where the limestone is free from sand or clay, but that proves only that they preferred the cleaner water; it has no bearing on the question of depth, for within a few yards the limestone shades off into calcareous shale. Condit's discovery of the Ames fauna near the western shore line, where the rock is sandy, conglomerate and wave marked, shows that the animals existed in shallow water. Butts's observations on the Ordovician fauna are equally definite. The evidence is so clear respecting the Pennsylvanian brachiopods, that one is tempted to believe about all the genera, as Schuchert has suggested respecting the rhynchonellids, that they were originally forms belonging to shallow water, and that the tendency of so many modern forms to prefer deeper water is a modification due to subsidence of coastal areas. As far as the testimony of brachiopods is concerned, there is every reason to suppose that the marine deposits were laid down in shallow water.

The pelecypods of the Pennsylvanian within the Appalachian basin are allied, for the most part, to families which in recent times have great vertical distribution. Pectens range from 2 to 200 fathoms; Limas from 10 to 150; Arcas from low water to 200; but aviculoid forms seem to go no deeper than 20 fathoms. At the same time, one must bear in mind that, while many genera have great vertical range, there is, in most of them, a large number of species which are confined to water as shallow as that preferred by *Lingula* and *Discina*. It is certain that most of the Coal Measures pelecypods thrived best where the water carried clay or sand and thrived poorly where pure limestone was deposited. Few pelecypods

were obtained from the limestone at the Mercer horizon but they abound in the calcareous shale; the Brush Creek limestone and black shale has abundance of brachiopods and pelecypods, the latter especially numerous in individuals; the Ames limestone has few pelecypods, specimens of the six recorded species being rare everywhere; whereas the underlying shales have yielded 17 species, most of them represented abundantly—and with them are several species of brachiopods. Wholly similar conditions exist in Devonian and earlier formations where pelecypods abound in sandstones and even in calcareous muds but are comparatively rare in the limestones.

Gastropods of the present day have great vertical as well as geographical distribution, but many genera and species of other genera have very limited vertical range. Respecting those of the Pennsylvanian, little can be said. Their mode of occurrence gives little clue to their habits, for many of the species are almost equally abundant in shale and limestone. The migratory tendencies of gastropods makes the evidence of scattered, even that of comparatively numerous individuals of doubtful value; but where a clay shale is crowded with specimens of two or three species, as is the case many times, there is little room for doubt respecting the habitat preferred by those species. One who has made collections at several localities would not hesitate to assert that many species of gastropods found in the Allegheny and Conemaugh preferred to live near the ingress of muddy water.

If one were to conclude from the occurrence of cephalopod remains, he might decide that the character of the water has been a matter of indifference, for, from the earliest appearance of those forms, they have been distributed in limestones, shales and sandstones, sometimes attaining great size in the last. In so far as the Coal Measures of Pennsylvania and Ohio are concerned, the writer has obtained few specimens from the limestones but he has collected very many from the shales. The distribution would indicate that muddy water was preferred. But this inference has no good basis. Cephalopods are migratory; modern types prefer pure water; but after death, the shell freed from the animal may float great distances to be dropped in any kind of bed. The presence and the distribution of cephalopods give no certain information respecting the con-

ditions. At the same time, it does appear strange that, if the older forms preferred clear water, they are found so seldom in the Mercer and Vanport limestones, formed in long estuaries, while they are so abundant in the muds which are associated with the Brush Creek and in those underlying the Ames.

It would appear that the distribution and the habits of invertebrate animals forms lend no support to the belief that the Appalachian basin, during Coal Measures time, was ever covered in whole or in part by deep water. The passage of muddy-water-loving pelecypods and gastropods into the more calcareous and even into the limestone areas, the occurrence of such forms in shale patches, lying within limestone areas with different but interlocking fauna, suggest that in the areas of limestone deposit also the water was shallow, that those were merely estuaries, bordered in great part by lowland areas with very sluggish drainage.

Cornet,[112] in discussing the lowest Coal Measures deposits near Mons in Belgium, regards the absence of gastropods, the abundance of pelecypods with byssus, especially of mytiloids, aviculoids and pectenoids, as evidence that the deposit was littoral. Modern conditions on the Belgian coast strengthen his conviction. The abundance of ammonoids might indicate deep water, but this cannot be decisive in the presence of contrary evidence. One can easily understand the presence of cephalopods in littoral deposits, but it would be difficult if not impossible to explain the great abundance of molluscs with byssus in deposits made far off shore. He says that Barrois had come to the same conclusion respecting the alum-bearing shales at Marly, but E. Haug has placed generally among deep sea deposits the shales and fine shaly sandstones with *Goniatites* and *Pseudonomya,* constituting the Culm. While the life indicates littoral deposition, the fine grain of the H la sediment seems to accord better with a certain distance from the shore. But this objection means nothing for, as actual conditions show, the coarseness or fineness of shore deposits depends on features of the area, its lithology, altitude and climate. The coal terrain, excepting intercalations only a few

[112] J. Cornet, "Le terrain houiller sans houille (H la) et sa fauna dans le bassin du couchant de Mons," *Ann. Soc. Geol. de Belgique,* Vol. XXXIV., 1906, Mem., pp. 139–152.

meters thick, is formed of very fine sediments. Clay shales make up about 70 per cent. of the column; nevertheless the Upper Coal Measures of the Franco-Belgian basin cannot be regarded as a deposit of the deep sea. He feels compelled to believe that the neighboring areas were lowlands and that the continent was in an advanced stage of peneplanation.

Jukes-Brown had reached the same conclusion respecting the English coal terrain.

Schuchert,[113] in the work already cited frequently, asserts that, during the periodic invasions in the Palæozoic, the depth of water in the Appalachian sea was very shallow, rarely exceeding 200 to 300 feet. On the west shore of Appalachia, conglomerates, sandstone and coarse muds, with rippled surfaces, are common; while in calcareous periods, one finds shrinkage cracks, marking great mud flats inundated periodically with calcareous materials nearly devoid of life. In the New York basin, the northern division of the Appalachian, the later deposits are sands and muds without marine life, though containing some land plants, some fishes and some fresh-water bivalves. The sands are often red, oxidized materials in estuaries, dried out by sun and air. The shallowness of the sea is evidenced by the almost endless list of formation names applied by field geologists. These conditions existed at the close of the Devonian.

Ulrich[114] in some instances would go farther than Schuchert in limitation of depth. These students had covered a very great part of the United States either by personal observation or by study of collections made by government geologists and others. They agree wholly in asserting that seas caused by ocean invasions were shallow, but Ulrich feels justified in admitting for some extensive areas a less depth than that which Schuchert, with abundant caution, had named as a probable maximum in his general statement. He had examined about 20 marine embayments of Ordovician and Silurian age in the Nashville and Ozark uplifts—the former within the area of Cincinnatia and the latter much farther west. His con-

[113] Schuchert, "Palæography of North America," pp. 438, 439.

[114] E. O. Ulrich, "Revision of the Palæozoic Systems," pp. 361.

clusion is that the depth of water was never more than 100 feet in those localities and generally much less. His studies led him to conclude that the average depth of Palæozoic seas was even less than 200 feet and that none attained a depth exceeding 600 feet.

There is no reason to suppose that the non-marine limestones are other than shallow water deposits; they are sun-cracked and rippled in some extensive areas. Equally there appears to be no valid reason for supposing that the marine limestones are of deep sea origin; at times, they are sun-cracked and wave-marked; at others they are distinctly near-shore deposits; yet the fauna, characterizing them at a distance from the shore, is present and the individuals are of such size as to show that the conditions were not unfavorable. The only ground for asserting that the limestones are of deep sea origin is the time-honored conception that presence of certain groups of invertebrates is proof that the water was deep. This conception itself stands seriously in need of proof.

Mode of Deposition.

Before taking up the study of coal beds, it is necessary to ascertain, if possible, the conditions under which the deposits already considered were laid down. Three possible hypotheses have been suggested.

The basin may have been a Mediterranean sea, 250 miles wide and more than 800 miles long, 4,000 to 6,000 feet deep, into which streams delivered débris until the whole area was filled.

The basin, originally almost wholly dry land, was brought under water by gradual but interrupted subsidence; inflowing streams formed deltas which eventually filled the basin.

The water-area, during most of the period, may have been comparatively insignificant. The two longitudinal valleys may have had each its own important river, with tributaries, which formed dejection cones, to be remodeled by floods and by meanders of the streams, while the whole region was subsiding slowly though not continuously.

The first hypothesis is altogether improbable. It involves the conception that the surface of the sea within the basin was at tide

level and that the water was excluded finally by deposition of mineral matter on the bottom. Under such conditions, it would be impossible to account for the formation of fossiliferous limestones and shales within narrow well-defined areas at 2,000 feet below the water-surface. It would be impossible to account for the distribution of conglomerates and pebble rocks, almost free from argillaceous matter, over great areas in the central parts of the basin, 100 or more miles from the shore and at a depth of several thousand feet below the surface. It would be impossible to explain the occurrence of sun cracks, ripple marks and clumps of plants *in situ,* which are found at so many horizons throughout the column. It would be almost impossible to discover a source for the material, which has filled this vast basin of not less than 200,000 square miles to a depth of 4,000 to not less than 6,000 feet. The Appalachian land at the north would have been very narrow, for Carboniferous beds, with coal, were forming in New England less than 175 miles away at the east; the lowland of Cincinnatia separated the basin from the Indiana region where coal deposits were forming, no more than 175 miles distant; while, at the northwest, the Michigan area was filling, at less distance away. The land area would be insignificant on all sides except due north; but one cannot accept that as the source, unless willing to assign to the Pennsylvanian a duration which would stagger the credulity of even the most generous geologist. The suggestion that the Appalachian basin was bounded at the east by a great fault seems to be inadmissible for there is no evidence that the fault exists. The Appalachian system of folding originated far back in the Palæozoic and continued through the Devonian and Carboniferous. Its faults with insignificant exception are overthrusts toward the west; but such overthrusts cannot explain the origin of the basin, which could be formed, if formed by a fault, only by a normal fault with hade toward the west.

Each of the other suggestions, somewhat modified, would seem competent to explain the phenomena; but this statement is general. In discussing a matter of this kind, one must endeavor to gain a birdseye view of the whole area, for a problem so vast in extent cannot be studied with a microscope. Many details have much

importance for the local observer but are without weight in a discussion of the whole; while there are others, apparently unimportant, of which the importance cannot be exaggerated. The difficulty is to distinguish essentials from non-essentials, for one's convictions long entertained exert much influence. In any case, this personal equation must affect interpretation of the record, so that the student must be content to offer only a contribution, leaving to another the completion of the work. It is necessary first of all to have a knowledge of present conditions.

Fayol,[115] in the third part of his work, has discussed the constitution, origin and formation of deltas, as bearing upon the deposit of sedimentary rocks and has given the results of experiments in the extensive settling vats at Commentry. After exposing the errors into which geologists have been led by imperfect observations in too limited areas, he proceeds to show that the lack of horizontality is not necessarily evidence of dislocation, first referring to Wegmann's[116] experiments on deposit of sediments upon an inclined surface. Where beds have been laid down on such surfaces, they pass by insensible slopes and curved lines from horizontality to inclinations more or less strong and modeled on the surface below; the same beds, thick in the low parts, become thinner in rising and imbricate with beds previously existing. In discussing delta deposits, one must distinguish carefully between the Alluvial or emerged and the Neptunian or submerged portions. The material may be either coarse or fine and the inclination may vary considerably.

Lake deltas, such as are seen in alpine areas, have abrupt affluents and the material near shore is coarse while fine stuff is beyond. The slope at the upper edge is from 25 to 35 degrees

[115] H. Fayol, Études sur le terrain houiller de Commentry. Lithologie et stratigraphie," Saint-Etienne, 1887, pp. 356–531. Though the writer dissents energetically from many of Fayol's conclusions, he cannot withhold the expression of admiration for the manner in which that author has recorded every observation, making the work a treasury house of suggestion and information. It can serve as a model. If other observers had followed the same method, one engaged in preparation of a monograph would not have so frequent occasion to lament the folly which led him to begin the work.

[116] *Bull. Soc. Geol. de France,* Vol. 7, 1850, p. 187.

but decreases until it is the same with that of the lake bottom. The slope at the shore varies greatly. In Lake Geneva, that of the Thonon delta is 30 degrees, but that of the Rhone is much less. As the delta advances, the river's mouth is carried forward, while the stream meanders and covers the Neptunian beds with alluvium, which is horizontal. This formation of the alluvium is sometimes so slow as not to interfere with vegetation, as in the chief deltas of the Alps, those of the Reuss, Aar and Rhone. Fayol describes some natural and artificial sections of lake deltas as illustrating the amount of transported material: he says that, above the confluence of the Aar and the Thiele, all lake basins have disappeared up to the Jura; alluvium from the streams, the growth of peat bogs and the work of man have converted them into prairies. Marine deltas differ from those of lakes as the waves and tides interfere with regular development. The deltas of great rivers differ yet more; the Neptunian deposits are more extensive and less inclined, there being beds of several thousand square kilometers with inclination of only some centimeters per meter. Little however is known respecting these deltas, information having been obtained from only a few borings. Enough, however, is known to prove that great deltas contain deposits of vegetable matter, that the beds are less coarse and less inclined than those of lacustrian origin. The arrangement of the beds is closely dependent on the agitation of the water, which in turn is dependent on the size of the basin.

After recounting his experiments, which he regarded as amply confirming his conclusions respecting the origin of the Commentry sands, shales and coal beds, Fayol returns to discuss the primitive inclination of sedimentary rocks. As the doctrine of primitive horizontality has had important influence in the formulation of doctrines respecting the formation of coal beds, he thinks useful to examine it to the foundation and to prove its falsity. He cites Steno, Elie de Beaumont and Dufrenoy, Lyell and Credner in favor of the doctrine, following the notes with a long quotation from Lyell[117] in which are described the irregular and steeply inclined deposits near Nice, which that author thinks had the present abrupt

[117] C. Lyell, "Elements of Geology," sixth ed., New York, 1866, pp. 18, 19.

dip from the beginning. Fayol regards this as an astonishing exhibition of inconsistency on Lyell's part, since the facts contradict Lyell's conclusions respecting original horizontality. The reader can determine for himself, by consulting the original work, how much reason exists for this exultation.

Fayol examines the facts. He asserts that Steno generalized after having examined only the alluvial deposits. The arrangement of pebbles parallel to the bedding is no proof of original horizontality; the slight average slope of the ocean bottom has no bearing on deposits upon lake bottoms, for the latter often have a comparatively steep slope. The average of the Mediterranean bottom is slight, yet deposits at the mouth of the Var have a dip of 25 to 30 degrees. Beds of vegetable matter are buried in the depths of present deltas, and these have been considered as beds formed on the surface above sea-level and carried down by subsidence, in some cases, to a depth of 150 meters; but geologists have reasoned erroneously from local accumulations of mud and peat in certain deltas, for from those they have reasoned to accumulations of hundreds of meters and to widespread oscillations of the surface. In fine, he accepts de Lapparent's conclusions respecting the stability of the earth's crust and fortifies his position by a long citation from that author. He is convinced that he has destroyed two errors: that the vegetable accumulations in delta deposits were of local origin at the surface; that alternations of freshwater and marine deposits are evidence of oscillation of the surface.

It is certain that no one can doubt the accuracy of Fayol's recorded personal observations and many of his conclusions are in full accord with those of other observers in the same field during the last half century. But one must hesitate before accepting some of the broader generalizations; they are clearly based on observations within too limited areas and apparently on a not wholly clear understanding of what observers elsewhere have recorded. His experiments on sedimentation were ingenious, were executed with great skill and perseverance; they excel, in all respects, the earlier investigations by Rozet, Wegmann, Constant-Prevost and others, yet, in reading the record, one is reminded of Hebert's remark that

it is not always possible in experiment to reproduce the complicated conditions existing in nature. It is well to learn the phenomena as recorded by others at some localities mentioned by Fayol.

De Rosemont[118] says that between Aspremont and Nice one sees the great mass of pebbles marking the Var delta. He notes some features which appear to have been overlooked by Fayol. This deposit extends northwardly to the rocks of Saint-Martin-du-Var, westwardly to Cheiron and southwardly to the sea. The homogeneous mass is 350 to 400 meters thick and plunges beneath the sea between Aspremont and Cheiron with a thickness of 500 meters. It is rudely stratified and the dip varies from 10 to 30 degrees. This is the delta of the Var, which was formed prior to the Pliocene. It is cut, almost half way to the bottom, by an old valley, now filled with bluish and yellowish clays, holding a Pliocene fauna. Still later, this Pliocene deposit was trenched along its whole length by the present river Var, which flows in a deep channel-way. The phenomena described by de Rosement show that, under certain relations of land and sea, the first deposit was laid down; that under other relations, the river dug for itself a broad channel-way in the coarse deposit; that under still other relations, the valley was filled with Pliocene muds; and that last of all, the whole mass being once more above sea-level, the river cut its way down in the muds. It may well be that the steep dips referred to by de Rosemont, Lyell and Fayol originated in a way different from that conceived by the last two authors.

The Aar delta, very small, was studied long ago by Martins,[119] whose investigation was extremely detailed. The stream enters at Meyringen an alluvial valley, along which it meanders for about 5 miles, until, in approaching Lake Brienz, it divides to form a petty delta, 85 meters wide at the lake shore. Coarse material is dropped at Meyringen and only fine stuff reaches the lake, where it forms a submerged talus. The lake is 8 miles long and a mile and a half

[118] A. de Rosemont, "Sur le delta du Var et la période pluviare," *Bull. Soc. Geol. de France,* III., Vol. V., 1877, p. 799.

[119] C. Martins, "Note sur le delta de l'Aar, à son embouchure dans le lac de Brienz," *Bull. Soc. Geol. de France,* II., Vol. II., 1845, pp. 118–122.

wide. The slope of the talus is 30 degrees near the shore but, within 300 meters, it falls to 20 degrees. The surface is covered with fine silicious sand, a homogeneous black mud, which also covers the lake bottom throughout nearly the whole extent. The talus must become continuous with the bottom deposit within three fifths of a mile. Martins thinks that the slope of the delta proper is 20 to 23 degrees, but is certain that the deposits are horizontal in most of the area, for Martins found the bottom a level plain.

The delta of the Rhone, at the head of Lake Geneva, was studied by De la Beche,[120] whose results have been presented summarily by Lyell. The lake is 37 miles long and 2 to 8 miles wide. The depth is more than that of Lake Brienz, varying from 20 to 160 fathoms, but only from 120 to 160 along the middle line. The Rhone enters at the head as a turbid stream but is limpid at the outlet. An old Roman town, at the shore 8 centuries ago, is now a mile and a half inland. The older portion of the delta, above that town, extends 5 or 6 miles and is a flat alluvial plain, little above the stream and covered with swamps. The surface of the submerged cone sinks very gradually and, at a mile and three quarters, merges with the bottom of the lake, which is covered with river mud. Fine and coarse materials alternate in the delta deposit. When snows melt on the mountains, the increased flow brings down sand, mud, vegetable matter and driftwood. In 8 centuries there has accumulated a formation, perhaps 600 to 900 feet thick and nearly two miles long, with strata only slightly inclined. Conditions are somewhat different where a delta is formed by a torrent having great speed and a moderate quantity of water. The depth opposite the torrent of Ripaille is 80 fathoms at half a mile from shore, so that dip of strata in that minor delta must be not less than twice as great as in that of the Rhone, or apparently not far from 10 degrees.

Gilbert's[121] descriptions and figures of the well-dissected deltas

[120] H. T. De la Beche, *Edinb. Phil. Journ.*, Vol. II., 1820, p. 107; C. Lyell, "Principles of Geology," New York, 1872, Vol. I., pp. 413–415.

[121] G. K. Gilbert, "Lake Bonneville," U. S. Geol. Surv. Monographs, Vol. I., 1890, p. 162.

of the Bonneville area show that the dips of layers are from 15 to 20 feet degrees near the top but they diminish downward, the layers being disposed in sweeping parallel curves.

Dejection cones are merely deltas formed in the air. They are all due to stream transportation, but they differ greatly in form. More than 35 years ago, Gilbert advised that the broad deposits with gentle slopes be termed alluvial fans, and that the term alluvial cones be restricted to forms with steep slopes and formed by the smaller rapid streams. The distinction is important, as confusion of the types in descriptions seems to have caused some misconception, and the steep slopes described by some writers are seemingly regarded as typical of all. Hogard[122] long ago found a slope of 35 degrees in dejection cones composed of solid and angular fragments. The greater slope is always shown by the less friable material and cones made in air have much steeper slope than those made in water. Surell's[123] studies in alpine areas were made in search of means for protecting mountain areas from ravage by rainfall. He found that the slope of a dejection cone depended greatly on the material of which it is composed. Mud usually accompanies torrents and, where abundant, it is the first material gathered. If the flow be thick, the mud surmounts obstacles and in drying, especially if calcareous, it becomes tough, preventing access of air and destroying vegetation. If it carry blocks or pebbles, it cements them and in this way many breccias were formed in the areas examined. The steepness of the slope, on which a deposit may be laid down, depends on fluidity of the mass. Gravels are deposited on slopes not exceeding two and a half per cent.; fragments, 25 centimeters in diameter or side, may be checked on slopes of two and a half to 5 per cent.; while blocks of half a cubic meter come to rest on a slope of 5 to 8 per cent. If the blocks be very large, the current drops them on rapids; in any event they are dropped at the head of

[122] H. Hogard, "Quelques observations sur les nappes et cônes d'eboulement et sur les lits de déjection des torrents," *Bull. Soc. Geol. de France,* II., Vol. VII., 1850, p. 186.

[123] A. Surell, "Étude sur les torrents des Hautes-Alpes," 2d ed., 1870, Vol. I., pp. 37–39.

the fan. These usually fall from the mountains, and the torrents, no matter how strong, cannot carry them far. The fine mud and sand are not deposited along the torrents but are carried out by the rivers to become fertile alluvium. He describes dejection cones made by the Adour, Garonne and other streams, which have become confluent and which are now gashed by diverging currents. In discussing modes of protection against devastation by torrents, Surell says that it is unnecessary to wait until the region has become reforested. "It suffices if the surface be carpeted with grass, brush or shrubs. The herbaceous plants and the brush, as completely as the trees, protect the surface of the soil, divide the streams which tend to ravine it, prevent abrupt concentration of the waters and absorb a certain portion in the spongy humus, which has formed at their foot." He devotes several pages to discussion of this topic and gives a long list of plants which take possession of devastated areas, some of them growing on naked rock.

One who examines only the illustrating figures given in textbooks is in danger of supposing that alluvial fans are of limited extent, confined mostly to comparatively narrow river-valleys with abrupt sides; but the conception would be erroneous. Gras,[124] in writing of alpine diluvium in southeastern France, says that a great area between the Rhone and the first calcareous mountain of the Alps is filled with clay, sand and pebbles. This thick mass extends northward to beyond Dijon and the Saône Valley and follows the Rhone southward to the Mediterranean shore. The chief development is in the Département of Isere, whence it becomes thinner southward. He recognizes a vast dejection cone, or, better, alluvial fan on the Dauphiny plain, whose summit is in the Grand Chartreuse chain and whose base has a radius of 70 to 75 kilometers. The materials came from the mountains at the east and contain the characteristic rocks of Mount Blanc and other areas, so that they have been transported far. The streams have heaped up pebbles to the thickness of hundreds of meters.

[124] Sc. Gras, "Sur la période quaternaire, dans le vallée du Rhone et sa division en cinq époques distinctes," *Bull. Soc. Geol. de France,* II., Vol. XIV., 1857, p. 207.

Drew's[125] description of conditions along the upper Indus are equally illustrative. Alluvial fans of tributary streams issuing from the highlands have a radius of about a mile and a slope of about 5 or 6 degrees, the extreme limits being 3 and 8 degrees. There are, however, other fans with steeper slope, but they are not alluvial—they originated as talus. The streams subdivide on the fans, which increase with regular form as each stream yields its contribution. The fans, originally independent, become united. Drew gives a figure representing the conditions along 30 miles, where the fans have become continuous and extend two miles into the valley. The boundaries of the original fans are still recognizable. Rivers cut across the deposits and the tributaries, in lowering the channels, form new fans at their outlets.

The conditions described by Drew resemble those seen along the upper Rhone. There one finds some cones with steep slopes at their head near the wall, clearly of talus origin, for they were formed by streams issuing from hanging gorges, like the very steep deltas in some Italian lakes, described by Taylor.[126] The high angle of slope reported by some authors must be due to this mode of origin. Along the upper Rhone as well as along the Adige, just as in the western states, the slopes of the greater alluvial fans are usually gentle almost throughout. Even the gigantic landslide, on the Adige near Rovereto, has a gentle slope where cut by the railroad, though covered with huge blocks. The areal extent of the fans depends on the width of the valley and the transporting power of the streams. There would be notable variations in a slowly subsiding area, especially if the subsidence were not continuous.

One may link this type of deposit with that of the great river-plains by a reference to conditions observed on the upper Nile. Falconer[127] cites Russeger, who says that between Khartoum and Sennaar, not less than 200 miles, the deposits are:

[125] F. Drew, "Alluvial and Lacustrine Deposits and Glacial Records of the Upper Indus Basin," *Quart. Journ. Geol. Soc.*, Vol. XXIX., 1873, pp. 441–471.

[126] F. B. Taylor, "Post-Glacial changes of Altitude in the Italian and Swiss Lakes," *Bull. Geol. Soc. Amer.*, Vol. 15, 1904, pp. 369–378.

[127] H. Falconer, "On the asserted Occurrence of Human Bones in the ancient Fluviatile Deposits of the Nile and the Ganges," *Quart. Journ. Geol Soc.*, Vol. 21, 1865, pp. 372–379.

1. River mud, like the Nile mud of Egypt, containing calcareo-argillaceous concretions.

2. Friable, fine and coarse conglomerate of quartz grains and pebbles, cemented by ancient mud.

3. Ancient Nile mud, indurated, with embedded iron-shot clay, silicious limestone and, in the ferruginous portions, marly concretions.

4. Fine and coarse conglomerate, cemented by ancient Nile mud and calcareo-argillaceous matter. It is very hard.

5. Dark gray freshwater limestone.

The beds are horizontal and 30 to 36 feet deep. Vegetable remains occur throughout, except in the uppermost bed; the whole is of freshwater origin, the fauna consisting of species now living in the Nile, accompanied by some land forms. These deposits are in the region of widespread floods, whose great areal extent is due to vegetation in the river channel, which the river cannot tear out. The type of deposit is different below the first cataract. Newbold[128] says that at Thebes one can recognize mica spangles from granite of the first cataract, but at Asfet in the Delta, the spangles are so minute that they can hardly be recognized even with aid of a lens. Pebbles are very rare in the delta area; but the composition and texture of the deposit vary according to position, coarse material being confined to the main channels and their borders; fine material alone reaches the Mediterranean.

In examining the great delta regions in search of possible explanation of conditions during Coal Measures times, one must not confine his attention to the lowland areas; he must consider also the alluvial plains extending at times hundreds of miles above the technical head of the delta, even to the region where tributaries bring down coarse materials. The story is continuous from shore to mountains.

The immense plain of eastern China is described[129] as curving around the mountainous region of Shan-tung and as extending southward from near Peking for about 700 miles with width of 150

[128] Lieut. Newbold, "On the Geology of Egypt," *Quart. Journ. Geol. Soc.*, Vol. 4, 1848, pp. 341, 342.

[129] R. K. Douglas, "China," Encyc. Brittan., 9th ed., Vol. V., p. 630.

to 500 miles. The greater part of this plain descends very gently toward the sea and, being generally below the level of the Hoang-ho, it is exposed to disastrous inundations attending the rise of that river. The flood of 1911 is said to have covered an area 45 miles wide and several hundreds of miles long. The plain is the work of the Hoang-ho conjointly with the Yang-tse-kiang. It is a vast swampy area, in great part devoted to rice culture. Pumpelly[130] has shown that the Hoang-ho has shifted its course many times during the historical period. A Chinese work, published in 1705, states that the course of the river was regulated by Yu, which makes probable that diking had been undertaken and the plain placed under cultivation fully 2,000 years before the Christian era began. Pumpelly republished nine charts, showing changes in the channel-way during 3,000 years. The stream is mighty, turbulent, subject to enormous annual increase of volume, due to rainfall on the distant Kuen-Luen mountains, and it has always been a source of terror to the millions inhabiting the plains. Dikes have caused elevation of the stream bed, which, prior to the last great change, was apparently higher than the adjacent areas from Whang-ho to the mouth, a distance of 400 miles. Before that change, which took place about 1850, the river flowed westwardly to the Yellow Sea, entering it south from the Shan-tung peninsula, about 50 miles in the same direction from Pei-chow or about 150 miles north from the Yang-tse-kiang. The breach occurred near Fungpeh in Suchan and the water flowed away to the Gulf of Pechele on the north side of the Shang-tung area. The passage was by way of the Tat-sing river, whose waters were increased to six times their former volume. The new mouth is more than 350 miles west of north from the old one. By 1858, the old mouth was dry; but in 1863, the river had not yet determined its new channel and water still spread over great tracts north from Tsinan, the capital of Shan-tung.

Blanford[131] states that the Ganges-Indus-Brahmapootra plain of northern India embraces about 300,000 square miles and is from 90

[130] R. Pumpelly, "Geological Researches in China, Mongolia and Japan," Smithson. Contr., Vol. XV., No. 202, 1866, pp. 46 et seq.

[131] W. T. Blanford, "A Manual of the Geology of India," Calcutta, 1879, pp. 391, 394, LX.

to nearly 300 miles wide. The lowest point on the divide between the Indus and the Ganges is 924 feet above tide, but, in fact, there is no dividing ridge between the two systems and a very trifling change would divert the water from one side to the other—and very probably such changes have occurred. No traces of marine conditions appear in upper India since the early Tertiary. There is no proof that the whole of the plain was at any time under water, nor is there any proof that is was not. The Eocene sea occupied the Indus valley to the foot of the Himalayas and extended eastward to Kuchann. But thence to the Gano hills, no trace of marine condition exists. If the Eocene sea occupied the Ganges area, it is strange that no marine forms have been found. The same statement applies to the Brahmapootra plain, which now is in great part too swampy for cultivation.

Medlicott[132] says that the Lower and Middle Siwalik formations are composed of immensely preponderating sandstone, with occasional thick beds of red clay and rare, thin, discontinuous bands of nodular earthy limestone—the sandstone itself being occasionally calcareous. Conglomerates prevail in the Upper Siwalik and they are often made up of the coarsest shingle, precisely like that in the beds of the great Himalayan torrents. Brown clay occurs frequently with the conglomerate and at times wholly displaces it. This clay, even when pushed to the vertical, cannot be distinguished, in hand specimens, from the recent plains-deposit and no doubt it was formed in the same manner as alluvium. The sandstone of the zone is exactly like the sand forming the banks of great rivers, but is more or less consolidated. The suggestion that the Siwalik hills are merely an upraised portion of the India plains was not wholly misleading. At one time, the mass was supposed to be of marine origin—a relic of the old notion that a water-basin was an essential condition for extensive accumulation of deposits, and that a sea-margin was needed for such a spread of shingle as is found in the Siwaliks. The same opinion prevailed concerning the plains themselves. But the ocean had nothing to do with the matter. The mountain torrents are laying down great masses of shingle and clay on the margins of

[132] H. B. Medlicott, ibid., pp. 524, 525, 541, 672.

the plains; the thick sandstones and sandy clays of the Tertiary are, in form and composition, similar to the actual deposits of the great rivers. The vast extent of the alluvial fans is illustrated by one example:

"In the range between the Jumna and the Ganges, clays are very subordinate and the conglomerates are formed of the very hardest quartzite pebbles, just like the shingle now found in the great mountain torrents. This portion of the range is, in fact, an ancient diluvial fan of the rivers Tons, Jumna and Ganges. The Jumna, after its confluence with the Tons, now flows very obliquely across the dūn and passes through the outer range far to the west of the point where it leaves the high mountains, having had to double around the immense accumulation of hard materials it had formerly laid down in front of that gorge."

The Indus is forming alluvial plains in several parts of its valley within Ladak. Medlicott asserts that there is no difficulty in distinguishing lake from alluvial deposits. The former are fine laminated and horizontal; but the latter are irregular, coarse and may or may not be horizontal.

The same author,[133] in a later publication, remarks that the whole plain seems to be covered deeply with alluvial deposits, for even at Ambala, in the upper Indus region, a boring has shown alternations of sand, clay and gravel with some calcareous clay. The sands are one to 41 feet thick; the clays, 3 to 40 feet; but the calcareous beds are thin, none exceeding 2 feet. On the Jumna, within the Gangetic area and at about the same distance from the Siwalik or sub-Himalayan range, large bowlders were found at 40 feet, whereas the largest fragment at Ambala is only five by two and a half inches and pebbles of moderate size are not of frequent occurrence. It is important to observe that no organic material has been found in the deposits on either side of the divide. Borings and excavations in all portions of the plain find the same alternation of sands and clays. The "technical" head of the Ganges delta, as it now exists, is where the Hoogly is set off, at 170 miles above Calcutta, which is 70 miles from the sea; the nearest edge of the recent alluvial plain is 80 miles west from that city—an immense area of level strata. The submerged portion extends far into the sea and its

[133] H. B. Medlicott, Rec. Geol. Surv. of India, Vol. XIV., 1881, pp. 220, 224, 225, 232, 234.

deposits are approximately horizontal. The depth of water in the Bay of Bengal is small, but outside of the delta area, there is a deep depression known as the "Swatch of no ground." All around it, soundings give a depth of 5 to 10 fathoms, but in the "Swatch" that increases abruptly to 300 fathoms. Fergusson,[134] cited by Topley, has shown that this space is kept open by currents, which may have kept it clear while the adjoining area was filling. In that case, the alluvial deposit would be at least 1,800 feet thick. A boring at Calcutta has proved it to be not less than 481 feet.

Lyell[135] relates that at no place in the delta proper or for 400 miles from the sea does one see any gravel, the whole plain of Bengal being overspread with Himalayan mud, homogeneous but becoming more sandy near the hills and occasionally containing abundance of land shells. Those who sail down the river in time of flood see nothing but a sheet of water in every direction, except here and there where the tops of trees emerge above its level. No reference to vegetable matter is made by Lyell or by any other observer to whose work the writer had had access—though the mud is exposed in river cliffs, 80 feet high near Calcutta. Lyell mentions the boring at Calcutta in which peat was pierced at 50 feet. Blanford, in the work already cited (p. 400), says that this peat bed is found at 20 to 30 feet from the surface in all excavations around the city and that it seems to extend under a large area in the surrounding country, having been met with in borings even to 35 miles southeast and to 81 miles east by north. Lyell states that this was considered to be an old soil, carrying a vegetation similar to that of the present Sundurbund. Logs and branches of red-colored wood occur above and below the peat, so little changed as to be identifiable, and they were recognized as the Soondri tree, now prevalent at the foot of the delta. In this Calcutta boring, clay, sand and pebbles were pierced at 120 feet and another forest bed was reached at 380 feet, while the boring ended in beds of pebbles, sands and bowlders. The conditions throughout suggest that, before sub-

[134] W. Topley, "India," Encyc. Brit., 9th ed., Vol. XII., p. 736.

[135] C. Lyell, "Principles of Geology," 1872, Vol. I., pp. 476, 477; "The Geological Evidences of the Antiquity of Man," New York, 1871, pp. 336, 337.

sidence began, the area was diversified with hills and valleys, now reduced to a common level by the mud deposit. One is not justified in referring to the evidence respecting the peat accumulations as unimportant; the observations embrace an area greater than that of all the coal basins within central France.

But similar conditions exist elsewhere on the India peninsula. Medlicott[136] published with comments the notes made by G. E. Ormiston during excavations for a government dock on Bombay island, on the west coast of India. In a space of about 30 acres, 382 trees and stumps were uncovered, of which 223 were erect. Some of the prostrate stems were without roots, but others had been overthrown in place, for the roots were still partly embedded in the soil. The stumps are rooted in a thin soil of decomposed basalt and are surrounded by a stiff blue clay on which rests black marine mud, 4 to 5 feet thick. Stumps projecting above the clay into the black mud have been drilled by *Teredo;* in some cases the holes pass downward through the trunk towards the roots and are filled with indurated clay. Medlicott states that the trees are *Acacia catechu;* two drifted logs of teak wood were found in the clay. This clay deposit must have been made very quietly, for a prostrate stem shows its branches and even delicate twigs in place. The soil was very thin and the roots spread out horizontally; the trees were large, one of the prostrate trunks being 46 feet long. How far the forest extends is unknown, as no investigations were made beyond the excavation of 30 acres.

But while the region of the Ganges and Indus have been subsiding more or less since the late Tertiary, there have been local elevations of no mean extent within recent time; and their character is such as to leave no room for doubting that they had many predecessors. Fergusson[137] notes the comparatively recent elevation of the Madorpora Jungh, at whose southern extremity the city of Dacca was built. This uplifted area is 75 miles long with an extreme width of 35 miles and a height of 100 feet on the west side toward the Brahmapootra. Fergusson describes in detail the shiftings of

[136] Records Geol. Surv. of India, Vol. XIV., 1881, pp. 320–323.

[137] J. Fergusson, "On Recent Changes in the Delta of the Ganges," *Quart. Journ. Geol. Soc.,* Vol. XIX., 1863, pp. 329, 333–350.

the channel-ways in the delta region, which is covered with silt. MacMurdo[138] published in the *Asiatic Journal* an account of the India earthquake of 1819. An extract was published in Edinburgh, which has been utilized by Lyell. This earthquake was felt within a radius of 1,000 miles from Bhooj, central in the Indus delta. The previous depth of the shallow eastern arm of the river was only one foot at ebb tide, but it was deepened to 18 feet; the village of Sindree, farther up the stream, was submerged and a lagoon was formed with area of 2,000 square miles. Immediately after the shock an elevated area was observed at the northeast, where previously there had been a level plain. This, the Ullah Bund, is more than 50 miles long, 16 miles wide and has an average height of 10 feet above the delta surface. The course of the Indus, as Lyell related, was much unsettled during several years, but in 1826 the river threw a great body of water into the eastern arm, which cut through all artificial dams as well as the Ullah Bund itself. The natural section, thus exposed, showed that the upraised land is of delta material. By 1838, the Sindree lagoon had become almost filled with detritus.

The area drained by the Po, the great plain of northern Italy, has received voluminous treatment from many geologists. A summary description of the area was given by Collie,[139] who says that the plain contains 11,000 square miles and that the mountain area, drained by it, is 16,000 square miles. Borings in the plain show that it is covered with approximately horizontal sand, clay and marsh deposits. The river, in spite of the enormous mass of inorganic materials brought down from the mountains, does little toward aggrading the lower channel, as the load is deposited in lakes whence clear water flows. The stream is thoroughly diked from Cremona to the delta marshes, and the dikes are placed at some distance from the channel, enabling the stream, when in flood, to overflow a considerable space before reaching them. This intermediate space is

[138] Captain MacMurdo, "Account of the Earthquake which occurred in India in June, 1819," *Edinb. Phil. Journ.*, Vol. IV., 1821, pp. 106–109; C. Lyell, "Principles of Geology," Vol. II., pp. 98–102.

[139] G. L. Collie, "Basin of the Po River," *Bull. Geol. Soc. Amer.*, Vol. 15, 1904, pp. 566–568.

covered in many places with willows and thick underbrush, so that the current's speed is reduced and there is little erosion of the dikes. The deposits on the plain of the upper Po are irregular and cross-bedded, consisting of cobbles, coarse gravel and pebbles with occasional wedges of sand. At times, local deposits of stratified silt and clay are seen, such as that near Turin, covering 40 acres. The deposits are more regular along the lower Po, much of the material being clay or fine sand, often laminated. In extended exposures, long, flat lenses of sand are shown, which are enwrapped by the finer sediments.

The plain of northern Italy receives drainage and deposits from the Alps and Appenines by way of the Po and its tributaries; from the Tyrolese Alps by way of the Adige; while smaller streams, flowing directly to the Adriatic, contribute their share toward extension of the plain. Taramelli[140] has gathered the information bearing on the development of the plain, with its sands, clays and occasional coral limestones. At the beginning of the Pliocene, it was in great part dry land, for great valleys were excavated, in which gravels were deposited. The topography, in its broader features, was well-defined at that time. During the later Pliocene, the region was invaded by the sea and deposits, termed marine Pliocene, were laid down. These have been recognized in much of Italy, which must have been an archipelago. But at the close of the Pliocene, irregular differential elevation took place, as appears from the altitudes correlated by Taramelli. It is clear that, after the Miocene, a great area was converted into dry land, to be brought again under the sea, but afterwards to be elevated in some localities to 700 meters above that level, while in others it is still below it. These Pliocene beds are the terraces of diluvial deposits.

De Collegno[141] has shown the wide extent of pebbly and sandy deposits in northern Italy and the relations of those deposits to the rivers. On the plain of Milan, the pebbles are often consolidated into a conglomerate, which is exposed along the river and in rail-

[140] T. Taramelli, "L'Epoca glaciale in Italia," *Atti Soc. Ital. Progr. Sci.*, Riunion IV., 1910, separate, pp. 5, 6.

[141] De Collegno, "Note sur le terrain erratique du revers méridional des Alpes," *Bull. Soc. Geol. de France,* II., Vol. II., 1845, pp. 284–286.

road excavations. He found that, south from Milan, the gravel is too fine for use in maintaining the roads, whereas, north from the city, ample material for that purpose is found just below the surface. From Turin to Verceil, the bowlders rarely exceed 50 centimeters; but, in ascending from Chivasso toward the valley of Aoste, by Ivrée, one finds great blocks of 40 to 50 cubic meters. This deposit is 400 meters thick at Ivrée, where one often sees 100 meters of conglomerate; it is 60 to 80 meters thick on the Adda and some borings on the left bank of the Po have been pushed 60 meters without passing through the detrital mass.

Martins and Gastaldi[142] remark that the alpine diluvium underlying moraine material is composed of pebbles, which decrease in size as one leaves the Alps. At the foot of the mountains they have a diameter of 40 to 50 centimeters, but at Turin they are rarely as large as a man's head. Small and large pebbles are present together and are mingled with sand and gravel.

Tacconi[143] studied collections from about 100 borings in and around Pavia, which is at the junction of the Po and the Ticino. He distinguished readily between the contributions made by those rivers, for glaucophane characterizes the Po material and staurolite abounds in that from the Ticino. Pebbles and gravels are wanting in the exposed deposits, diluvial in the terraces but alluvial in the valley; in some collections, however, especially in those from the deeper borings, coarse sand and small pebbles are abundant. The usual color of the sands is ashen-gray, but some specimens are yellowish, the tint being due to alteration of ferruginous constituents. These are from different depths and Tacconi conceives that these layers of alluvium may have been exposed to the air for considerable periods before burial under later deposits. The distribution of minerals leads him to suppose that, during the diluvial epoch, the great rivers, descending from the Alps, united in the Lombardy plain

[142] C. Martins et B. Gastaldi, "Essai sur les terrains superficiels de la vallée du Po, aux environs de Turin, comparés a eux de la plaine Suisse," *Bull. Soc. Geol. de France,* II., Vol. VII., 1850, pp. 587–589.

[143] E. Tacconi, "Sulla composizione mineralogica delle alluvioni constituenti il sottosuolo di Pavia e dintorni," *Rendic. R. Ist. Lomb.,* II., Vol. XXXIV., 1901, pp. 873–881.

and covered a vast area with water, so as to spread the mingled sediment of many water courses over the whole.

The north-central portion of the Italian plain certainly resembles closely a confluent flood-plain. The Adige emerges from its valley just above Domigliana and, before reaching Verona, it is flowing in the broad plain. It has brought down immense quantities of very coarse material; for many miles it flows on a thick bed of pebbles, derived in great measure from the Tyrolese Alps. At Ala. where the river enters Italy, bowlders, 2 feet in diameter, are not uncommon, but the surface material of the flood plain is not coarse, except along the lines of filled watercourses. West from Verona, along the railroad there is no rock exposure, all is river detritus. At many places, the cobbles are so large that the peasants gather them for construction of fences; pebbles large and small are shown in the railroad excavations between Verona and Milan, but they are in sands; the lines of stream flow are not shown in any excavation visible from the road. The material decreases in coarseness very quickly toward the south. Pavia is about 30 miles south from Milan, but no coarse material is found there; Piacenza is about 40 miles south from Brescia where the deposit is very coarse, but at the former city the materials are fine. The Po has been crowded to the south side of the plain, but it has changed its course many times and the deserted channels are distinct.

Morlot maintained that advance of the plain into the Adriatic has been continuous in spite of long slow subsidence and he asserted that, within the historic period, this subsidence has amounted to 5 feet; but the grounds for his assertion have been disputed. Evidence exists which cannot be disputed, which proves long continued subsidence. Challaye[144] reported that a boring made by Dagousse at Venice on the Piazza-de-Santa-Maria-Formosa passed through 132 meters of sand, clay and peat. Micaceous sand prevailed to the depth of 25 meters and beds of peat were pierced at 29, 48, 85, and 126 meters. He asserts that the peat in these beds is absolutely the same as that forming now at several places within the lagoon. Challaye finds evidence in this boring that, including the growth

[144] C. A. Challaye, *Bull. Soc. Geol. de France,* II., Vol. V., 1848, pp. 23, 24.

on the present surface, five forests have flourished on this spot. Many borings have been made in this immediate area and the evidence is consistent throughout. Tacconi[145] has discussed the record of one, which was driven 197 meters without passing beyond the clays and sands. Well-marked peat beds were found at 18.80, 29.15, 32.80, 46.50, 56.70, 86.80, 129.80, 151.50 and thin streaks down to 165 meters. It is quite possible that some of the very thin streaks of carbonaceous material may be composed of vegetable matter brought down during floods, but the suggestion of similar origin for the thicker deposits, as made by some writers, cannot be entertained. In view of what is known respecting the ability of floods to remove the plant cover, the suggestion must be regarded as pure assumption; the Po of the present day is confined within dikes, yet it cannot sweep the enclosed narrow flood plain clear of willows and underbrush; there is no reason to suppose that the unconfined stream was more efficient. Moreover, the material brought up from the borings is peat, not a mere agglomeration of vegetable material, but peat, such as now accumulates at the surface. Tacconi emphasizes the fact that peat is more abundant in the upper portion of the deposit, the important beds being within 18 and 59 meters; and he notes especially the bed at 18.80, which is 2.6 meters, and that at 29.15, which is 6.25 meters thick, and, like some of the others, contains wood. The lower beds are thinner and increasingly impure, which leads him to suppose that conditions were less stable, that the river courses were changed more frequently in the earlier than in the later stages of deposit. The materials pierced by this boring are mostly fine, only one layer of coarse stuff having been found. The thickest clay bed is 8 meters and the thickest sand deposit is 24 meters.

The Mississippi region has been described so minutely by many authors that only passing reference to some details is necessary here. The delta, as usually limited, begins at a little way above the Red River of Louisiana, but in Tertiary times the water area

[145] E. Tacconi, "Sulla composizione mineralogica della sabbia di un pozzo trivellato al lido di Venezia," *Atti R. Ist. Veneto,* Vol. LXX., 1911, pp. 655–665.

reached almost to the mouth of the Ohio, so that the river bluffs show Tertiary and Quaternary deposits. The broad space, covered with alluvium, extends northward to St. Louis and is continuous thence up the Missouri, which is the main stream, the upper Mississippi being only a tributary. This alluvial area, subject to flood prior to construction of levees, is 40 to 70 miles wide from the mouth of the Ohio to the head of the delta, below which it expands to a maximum of about 130 miles. The area contracts above the Ohio, so that, along the Upper Mississippi and the Missouri, it frequently is less than 5 miles wide.

The nature of the river bed varies. From the head of navigation to the mouth of Maria's river, the Missouri, with velocity of 2.7 miles per hour, flows on loose gravel; but farther down in the loess region the bed is shifting silt. In the lower course of the Mississippi, the river has cut its way to the Tertiary beds, which for long distances are swept clear of later sediments by the current. But samples, taken from the bottom at many localities between the Ohio and the Gulf, show that immense deposits of pure silicious sand and fine gravel, wholly free from river mud, exist in the channel-way. These are found below channel-chutes, at all angles to the direction of flow, sometimes even parallel with it; but they rarely extend from one side to the other. The velocity of the water at such places is too great to permit much deposition but is insufficient to wash away the sand. The materials become finer as the Gulf is approached. The bar at the mouth of Southwest pass is of sand and mud, soft mud being inside and around the shoal, while the surface material is much harder, containing much sand. The bar at the mouth of South pass is chiefly sand with spots of soft mud, but away from the shoal, the bottom is covered with soft yellow and blue mud of the passes.

Studies were made in 1851 to ascertain whether or not material was pushed along by the river. A keg was laid on the bed in such fashion as to retain suspended matter while permitting unimpeded flow of the water. Coarse sand with some clay was obtained at many localities, while at others only coarse sand remained in the keg. Near the mouth of Red River, at the head of the delta, the

samples consisted of small gravel and coarse sand with very little clay. No coarse material is carried beyond New Orleans but pebbles occur in the lower alluvium near that city and the bars at the mouths of the passes show very distinctly the effect of sorting. The source of the coarse material was not determined, but in any event it is certain that the gravels had travelled hundreds of miles.[146]

The story has been continuous along the Mississippi since early in the Tertiary. The river has made its valley in the soft rocks forming its bluffs, where successive deposits are exposed. In the later Tertiary as well as in the alluvial deposits, one sees the cypress swamps which at one time were at the surface. The erect stumps and fallen trunks are present, the condition being wholly like that in recent swamps, except that the trees are dead. Forested and buried swamps are numerous and of great extent on the alluvial plain below Red River, but their area has been diminished by drainage and the protection afforded by levees. The buried swamps, supposed at one time to be composed of drifted vegetable matter, are known now to be *in situ*.

It is not always easy to draw the line between delta deposits and those made on flood plains, as is evident from Medlicott's observations on the Indo-Gangetic region. Belt's[147] studies in a portion of the Siberian plain may be taken as complementary to those by Medlicott, for they show how widely coarse material may be distributed by rivers. Leaving Ekaterinburg, he reached the level, sandy region of the steppe within 60 miles and continued his journey in east-southeast direction to Ischim, on a tributary of the Irtisch, where the steppe wall, 80 feet high, is composed of sand without pebbles and partly cross-bedded. Thence to Omsk on the Irtisch, the plain is monotonous but at that city he saw a section showing 60 feet of the steppe deposit, in which the sand, at times cross-bedded, contained lines of pebbles, none larger than a cherry, with here and there broken shells of *Cyrena fluminalis*. At Omsk, he

[146] A. A. Humphreys and H. L. Abbot, "Physics and Hydraulics of the Mississippi River," 1876, pp. 45, 90, 92, 147, 673.

[147] T. Belt, "The Steppes of Siberia," *Quart. Journ. Geol. Soc.*, Vol. XXX., 1874, pp. 490–498.

changed his course and ascended the river 253 miles to Pavlodav. The numerous natural sections had the same structure and composition as at Omsk, except that the pebbles increased in number and size, becoming as large as a walnut within 100 miles. The section of the deposit at Pavlodav is

	Feet.
1. Soil.	
2. Stratified red sand, with lines of small gravel	20
3. Light colored sandy silt	8
4. Coarse, clean sand, with lines of small pebbles and one line of coarse pebbles	15
5. Clayey silt, not laminated; fragments of bed rock in the lower half	6

resting on magnesian limestone. The river at this place flowed on the edge of an alluvial plain 6 miles wide. He crossed at Pavlodav and travelled southwest seeking the source of the pebbles. At about 60 miles from that city, his wheel jolted on the first stone encountered during the ride of nearly 1,000 miles. Thenceforward, angular fragments of quartz were abundant and within a short distance he reached exposures of crystalline rocks. Belt was inclined to believe that ice had impounded the fresh water into a lake, but Ansted had asked, whence came the water to make the freshwater lake of nearly 3,000,000 square miles, in which the steppe deposits were laid down, and also, if there had been the lake, what has become of the water. Ramsay[148] conceived that, if we could imagine the vast flat territory of Siberia with its mighty rivers facing south to a sub-tropical sea, we would have something like the Carboniferous. Coal beds do not indicate old lakes but continental areas, through which rivers meandered.

Reference was made on an earlier page to Kuntze's[149] description of conditions in the Paraguayan region, but other writers have gone into more detail respecting some features requiring consideration here. Church[150] says that a vast area in the Plata region is

[150] G. E. Church, "Argentine Geography and the Ancient Pampean Sea," *Rep. Brit. Assoc. Adv. Sci.*, for 1898, pp. 932–934.

[148] A. C. Ramsay, "Physical Geology and Geography of Great Britain," 5th ed., London, 1878, p. 139.

[149] O. Kuntze, "Geogenetische Beitrage," 1895, pp. 67, 68.

covered to a depth of 20 to 100 feet with a reddish-yellow semi-plastic earth, frequently marly with calcareous nodules, due to percolation of calcareous water from the rivers. No stones or pebbles are seen in this deposit, but it grows more sandy toward the west. Church believes that these Pampean deposits were laid down in a sea, 1,400 miles long and with an area of about 600,000 square miles, this being the region now drained by the Paraguay and its tributaries, the Pilcomayo, Bermejo and Salado at the west, and the Lourenço, Parana and Uraguay at the east. To this area he would add about 115,000 square miles at the northwest, now drained into the Amazon by the Madeira River, the areas being connected by a narrow strait. This inland sea communicated with the ocean near the present outlet of Rio de la Plata, but the area of deposit extended farther southward, almost to the latitude of Bahia Blanca. The Pampean beds have been displaced and made irregular in some places, but they are undisturbed in the southern portion of this Gran Chaco region between the Bermejo and Salado Rivers. Church estimates the present area of the muds at about 400,000 square miles and believes that they were deposited in shallow water. The rivers are all very crooked, have very uncertain channels, at times deserting the old course for a new one several miles away. They frequently divide and subdivide so as to break the plain into narrow but extensive islands.

Kerr[151] has described the central part of the plain. The Bermejo River, entering from the west, is 1,000 miles long but very tortuous, the distance in direct line from its source to the Paraguay River being not more than 450 miles. The speed is 4 to 5 miles per hour and an enormous amount of solid matter is carried in suspension—whence its name, "The Red." In flood time, it is almost liquid mud. The rainfall is very heavy and the maxima are marked by inundations covering immense areas to the depth of several feet. Areas subject to inundation are characterized by palm forests, and one may always see on the trees a dark line at 3 to 5 feet above the ground, marking the flood level. The surface layer,

[151] J. G. Kerr, "The Gran Chaco," *Scot. Geogr. Mag.*, Vol. VIII., 1892, pp. 74–77.

deposited by the flood, divides during the dry season into pentagonal columns. Remedi, in the same magazine for 1897, says that the Bermejo drops its heavy load, fills its channel and is compelled frequently to take a new direction. Trunks of trees, lodged on the bottom, soon lead to formation of dams and to diversion of the stream.

The Chaco Oriental is north from the Pilcomayo River, which enters the Paraguay near Asuncion, somewhat more than 100 miles above the mouth of the Bermejo. This part of the area was studied by Smith.[152] The Paraguay River, north from Asuncion, is very near the highland at the east, but west from the river the Chaco is always low and the plain extends far inland to the high table land of Bolivia, which is said to fall off abruptly toward the east. The Chaco is covered with water during heavy rains. Above the mouth of the Bermejo, the region is forested, but farther north are great areas with only scattered Carauda palms and no other vegetation. In lat. 21° 26′ 40″ S., the river issues from a gorge through rocky hills, which, toward the east, are well connected with the Brazilian highlands; but, west from the river, there seems to be a series of isolated hills rising from the Chaco, whose relation to the Bolivian highlands is unknown, as the region has not been explored. Above this gap, known as Fecho dos Morros, vegetation changes, the palms disappear and one sees only open grass land with bushes and a forest fringe on the river banks. These upper lands are covered almost wholly when the river, which rises 50 feet, is in flood. All this flat country from Fecho dos Morros to Villa Maria, a distance of 400 miles, is subject to floods, which are greater toward the north. At the mouth of São Lourenço, the area flooded during high water is not less than 150 miles wide. The whole is a labyrinth of lakes, ponds, swamps and channels in a grassy plain, there being forests only near the river bank. It is more remarkable in this respect than the Amazon flood plains, for even at low water one fourth of the area is covered. When the river is highest, the whole

[152] H. H. Smith in J. B. Hatcher, "Origin of the Oligocene and Miocene Deposits of the Great Plains," *Proc. Amer. Phil. Soc.*, Vol. XLI., 1902, pp. 113–131. The communication by Smith is pp. 128–130.

region is a vast lake with floating grass and weeds, only a few islands remain here and there, on which wild animals find refuge.

Near Bahia Blanca, just beyond the limits of the Pampean deposits, Darwin[153] found pebbles of quartz on the coast which must have travelled 45 miles. The Tertiary beds of Patagonia are capped by a conglomerate, extending northward from the Strait of Magellan about 800 miles with an average width of 200 miles and an average thickness of 50 feet. Its porphyry pebbles came from the Cordillera. The rock was derived from masses falling on old coast lines and on river banks. The country is terraced, which leads Darwin to see in the phenomena the influence of wave action on the rising coast. He describes graphically the clashing of fragments as they are driven along by torrents in flood.

Conclusions.

That a sea or an ocean is needed for accumulation of thick sedimentary deposits has been long a prevalent opinion among geologists. It is a survival of the period when observation within narrow areas provided a warp of fact to be filled in with a woof of fancy, when cataclysms were thought the rule of nature and modern conditions were believed to be exceptional in the earth's history. It so pervades geological literature that one, in disputing the doctrine, is very apt to employ conventional phrases which concede it. When the study of actual conditions had been prosecuted systematically, when phenomena in great and widely separated areas had been ascertained and compared, it became evident that the accepted doctrine was at least defective. During the last quarter century, intimate study of Quaternary deposits in Europe and America, as well as detailed investigations in physical geography—due largely to the initiative by W. M. Davis in America and A. Penck in Europe—has developed anew the conception that, great as has been the work of ocean forces, that of land forces has been vastly greater. As Ramsay saw for Siberia and Medlicott for India, the activities of rivers in conveying and distributing deposits far from the sea have brought about almost

[153] C. Darwin, "Journal of Researches," New York, 1846. Vol. I., pp. 96, 137, 138, 219.

inconceivably great results. Apparently the first distinct formulation of the new presentation in America was made simultaneously by Barrell and Grabau,[154] each of whom utilized phenomena of the Appalachian basin in illustration. Barrell's elaborate memoir discusses the subject in all its phases and merits careful study. He exhibits clearly the important part which river plains played in the Appalachian history down to the close of the Carboniferous. Grabau lays stress on the progressive overlap away from the source of supply, which, when associated with other facts, becomes an important element of the argument.

Study of the facts presented on the pages of this memoir has forced the writer to a conclusion very different from that hoped for when this investigation was begun.

The widespread horizontality of the Coal Measures deposits, coarse and fine alike, recalls conditions observed on the Siberian Steppe and other river regions. The folding of the beds proceeded from a common cause, lateral pressure applied at the east. The violence of plication decreases with notable regularity toward the west, until in western Pennsylvania and in Ohio, along a line of more than 100 miles, the folds become so gentle that they can be traced only by close study. Dips of more than one degree are unusual, while at times and for considerable distances the dip is barely one half of a degree. The same condition exists in a great part of West Virginia. The regular decrease in steepness of the folds leads to the belief that originally the beds were, to all intents, horizontal throughout the basin, the condition being that observed on the great river plains of comparable extent. The rare occurrence of driftwood in the widespread deposits is characteristic not only of the Coal Measures but also of vast river deposits, those of the Amazon, as described by Brown, and of the Ganges as described by Medlicott and Lyell. The long narrow areas of coarse to pebbly sandstone, often with driftwood, recall the filled valleys of the Sierra, described by LeConte, as well as filled deserted bows on the

[154] J. Barrell, "Relative Importance of Continental, Littoral and Marine Sedimentation," *Journ. of Geol.*, Vol. XIV., 1906, pp. 337, 338, 539–541; A. W. Grabau, "Types of Sedimentary Overlap," *Bull. Geol. Soc. Amer.*, Vol. 17, 1906, pp. 635, 636.

Mississippi and the filled channels so often disclosed when a stream in flood cuts across its "bottom." The distinct evidence of sorting of materials in the red shales, where clay and sand are in dovetailing lenses, as well as in some conglomerates, where hardly enough fine material remains to bind the pebbles, leaves little room for doubt that the work was done by streams moving rapidly in some cases, slowly in others. The pebbles are not flat, such as one may find on a shore, but oval or sub-spherical, river pebbles, and their gradual decrease in size as well as number in certain directions shows that the materials were rehandled many times. The rounded pebbles of coal and carbonaceous shale prove equally with those of quartz and sandstone that the deposits, whence they came, cropped out and were exposed to attack by streams of water. The marine limestones, with one exception, are in definite, long, narrow and comparatively insignificant areas, and pass, at the borders, where those remain for observation, into sandstone, chert or shale, the condition being that of an estuary surrounded by lowland, whose rivers bring a minimum of sediment. The shallowness of the water by which sediment was distributed and the short duration of the flooding are disclosed by wave marks, sun cracks and footprints of animals, occurring at so many horizons, while the moderate depth of the estuaries, in which limestone was formed, is apparent from the shore conditions of the limestone. The testimony of the fauna is confirmatory; that life needed not deep water, for it persisted to the very shore line in Ohio. Unconformability by erosion or by overlap marks the contact of Pennsylvanian with the underlying Mississippian in almost the whole basin, showing that the great part was dry land.

The record appears to show that the Appalachian basin, between the Alps-like Appalachia at the east and the low-lying Cincinnatia at the west, was divided longitudinally by the flat-topped and only moderately high Alleghania. The deepest portion of the eastern valley lay close to the foot of Appalachia, whence the surface rose westward almost inperceptibly to the crest of Alleghania. The western valley extended as a plateau with its low line crossing eastern Ohio in a south-southwest direction and deepening southwardly. The thickness of deposits in the two valleys is no index to the difference in altitude of the surface; the eastern valley is coincident with the

ancient trough of great subsidence, where deposits, throughout the Palæozoic, attained great thickness and whence they decrease quickly toward the west. The assertion of greater altitude for the western valley is based on absence of all deposits earlier than those of the latest New River in the northern half of the area.

Each basin had its longitudinal river. That of the east, rising in the present confines of New York, flowed with low gradient for more than 1,000 miles, receiving many tributaries from the bold Appalachia and many, perhaps, unimportant tributaries from the gentle slope at the west. Flowing at first close to Appalachia, it was pressed constantly westward by alluvial fans and cones, which became confluent and finally were modeled into a vast river plain. The main stream was sluggish and often interrupted; during high floods, the surface was covered broadly by a sheet of water and the débris from different streams was mingled. The river in the western basin received no débris-laden tributaries from east or west, except at the extreme north; it was more rapid than that in the east and pushed its coarse materials far southward. Progressive overlaps show that subsidence prevailed throughout the basin until the later stages, when it was confined to the contracting area of deposit; but it was differential and not constant. There were long intervals of slight or no movement during which rivers, reduced to base-level, distributed mostly fine material along their lower reaches. At the close of the Pottsville, the valleys had been filled and Alleghania had become buried; the whole area of deposit was an irregular marshy plain. But the old drainage systems continued until near the close of the Conemaugh and determined the lines of sea invasion; they disappeared only with changes in the topography, induced by the forces which were eventually to obliterate the basin. During the whole of the Pennsylvanian, a very great part of the basin was near sea-level. After the close of the Pottsville, few portions of the area of deposition seem to have been more than 300 feet above tide and there is no reason to suppose that any portion was at any time much more than 100 feet below tide.

The writer has become convinced that one must seek explanation of the phenomena of the Appalachian basin in those of the great river plains of modern times; and the phenomena of the Appalachian basin are those of coal regions elsewhere.